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Design and Development of a Wind Turbine with Flanged Diffuser Operating in Low Wind Speed Regime

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Abstract

In this paper, the performance characteristics of a fabricated Horizontal Axis Wind Turbine (HAWT) with and without flanged diffusers were studied using wind tunnel experiment. Measurements of global parameters (power, torque, rotational speed efficiency, etc.) were carried out at wind speed regime between 3-7 m/s. Flanged diffusers of five different inlet-outlet diameter ratios were employed. The results showed minimum mean increments in Tip-Speed Ratios (TSRs) of about 45% with the smallest diffuser and a maximum of 80% with the largest diffuser. Increments in the torque even at modest wind speed of 4 m/s were as much as 65, 70 and 76% for the largest three diffusers and about 33% for the smaller diffuser. The power output (with and without diffuser) gradually increased from 3-7 m/s wind speed, while the power coefficient (Cp) increased from 3-5.5 m/s, and thereafter began to fluctuate as the wind speed approached 7 m/s. Comparatively, maximum C_p of the turbine without diffuser was 0.22 for $\lambda = 0.534$ at a wind speed of 7 m/s, while the maximum average value of C_p for turbine with flanged diffuser 3 was 0.34 for $\lambda = 0.706$ at the same wind speed. As a result of the flanged diffuser attachment, the maximum C_p increased by 36%. The results showed mean incremental values of 52 and 57% with the greater value obtained from the second largest diffuser (Di/Do = 0.70) and the least value from the largest diffuser (Di/Do = 0.80), while the first three diffusers achieved near identical increments of 55%. This consequently implies that increments in the extracted power (i.e., C_p) above 5 m/s wind speed declined with indications of separation and turbulence in the flows beyond the rotor.

Keywords: Model, Fabrication, Horizontal, Wind turbine, Flanged diffusers, Power output and power coefficient.

1 | Introduction

The improvement and availability of renewable, clean energy has become an area of great interest in recent time, due to the deleterious serious effects of global warming and rapid depletion of fossil fuels. In order to address the current energy crisis various means of alternative energy have been evaluated in a number of literature, hence, wind energy technologies are one of the most firmly promising energy sources in the world and it symbolizes a feasible alternative, as it is a virtually endless resource. However, in comparison with the overall demand for energy, the scale of wind power usage is still very meager [1], [2]. Wind energy is the World's fastest-growing energy source that can power homes, businesses and industry with clean, renewable electricity for future benefits.

Interestingly, people are also realizing that wind power is one of the most promising new energy sources that can serve as an alternative to fossil fuel-generated electricity.

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As population of Nigeria increases and people strive for a higher standard of living, the amount of energy required to sustain the society is on the increase. On the other hand, the availability of renewable energy sources, particularly liquid fuels, is rapidly depleting. Among the various means of renewable energy, wind energy technologies have developed rapidly, and has played a vital role in the field of renewable energy. However, in comparison with the overall demand for energy, the scale of wind power utilization is still very small; especially the level of development in Nigeria, as government and private organization pay little or no attention to wind power generation [3].

To this effect, various causes are conceived such as: limited local area suitable for wind power plants, low wind speed regimes, the complex terrain environment compared to those in European or North American Countries as well as turbulent nature of the local wind. Hence, the introduction of new wind power system that produces higher power output even in areas with lower wind speed regime, and complex wind patterns expected is strongly desired. Therefore, ways for a large increase in output should be employed, if possible, to create a slight increase in the velocity of the approaching wind to a wind turbine. Therefore, if the wind speed can be increase by utilizing the fluid dynamics concept around a structure or topography, or if the wind flow is concentrate within a particular axis, then the power output of a wind turbine can be increased substantially [4], [5]. Researches have shown that there are two parameters that affect the value of the power output in a wind turbine, which are: the swept area of the blades and the wind speed. Therefore, one of these parameters can be increased by incorporating a flange diffuser at the exit of the wind tunnel. Shahsavarifard et al. [6] understudied a work on Diffuser Augmented Wind Turbine (DAWT), which focuses on concentrating wind energy in a diffuser with a large open angle and boundary layer control with several flow slots to realize a flow that goes along the inside surface of the diffuser. Abe and Ohya [7] investigated the flow fields around flanged diffusers to develop small type wind turbines using Computational Fluid Dynamics (CFDs). Results showed that the performance of a flanged diffuser strongly depended on the loading coefficient as well as the opening angle because it greatly affected the nature of the separation appearing inside the diffuser. Researchers evaluating the effects of flange diffusers on wind turbines revealed that loading coefficient for the best performance of a flanged diffuser was considerably smaller than that for a wind turbine without flange diffuser. It also showed that the flanged diffuser significantly increased the power and torque outputs, and rotational speed of the turbine [7], [9]. Abe et al. [10] also carried out experimental and numerical investigation of flow fields behind a small wind turbine with a flanged diffuser. Results showed that the power coefficient of the shrouded wind turbine was about four times that of the wind turbine without flanged-diffuser. Ohya et al. [11] examined the optimum form of the flanged diffuser, and demonstrated that power augmentation by a factor of about four to five is possible, compared to wind turbine with no flanged diffuser. Although the majority of the diffuser developments were done for the Horizontal-Axis Wind Turbines (HAWT), there are few works that focused on diffuser design for Vertical-Axis Wind Turbine (VAWT) applications. Takahashi et al. [12] studied the behavior of rotor blade tip vortices of a wind turbine equipped with a brimmed-diffuser shroud. Ohya [13] proposed the use of control plates attached to the body of a diffuser to create a more structured vortex flow. Based on a study on rectangular bodies, it was observed that flow around the controlled plates created a stronger vortex shedding.

Matsushima et al. [14] studied the effect of diffusers' shape on wind speed. They observed that the wind speed in diffuser without a flange in comparison to that of Abe et al. [10] was greatly influenced by the length and expansion angle of the diffuser, while the maximum wind speed increased 1.7 times with appropriate diffuser shape.

For wind power generation, particularly in Nigeria, low wind speed prevalence in majority of locations in the country is a major limitation. While the average wind speed at a potential wind farm site is critical, wind energy is, in general, a very diffuse energy. This is due to the low density of air as compared to, for example, water, which is 800 times denser. Therefore, the development of a wind power system with moderately sufficient output in low wind speed regimes and even at low cost for effective harnessing of wind energy, through a flanged-diffuser becomes necessary.

This works is aimed at designing a wind turbine with flange diffusers in order to study the performance characteristics (global parameters) of a wind turbine operating in low wind speed regime, with and without a mounted flanged-diffuser on its downstream side. In other words, a wind turbine designed with flanged diffuser operating in low wind speed regime is considered, for appraising the performance characteristics of global parameter of a wind turbine with and without a flanged diffuser. The objectives are to: measure the basic parameters of wind speed, torque and rotational speed of the wind turbines in controlled experiment with and/or without a flanged-diffuser; compute other parameters like power output, power coefficient and the Tip-Speed Ratio (TSR) from the basic data; measure wake velocities just behind the rotor and at the tip of the flange of the diffuser as a data base for future CFD studies; and to compare the obtained results for the wind turbine without the diffuser with those for the turbine with the diffuser. The principles behind incorporating a flanged-diffuser to a wind turbine is to act as an accelerator, i.e., increase the extracted power output by increasing the mass flow of the wind velocity that approaches the wind turbine. Therefore, the introduction of a novel wind power system that can produce higher power output even in areas where lower wind speed is expected was successfully achieved, vis-à-vis, enhanced the power and torque coefficients, thus, other parameters accordingly. Lastly, an understanding of the performance characteristics of the power output augmentation gives a more effective and efficient design of a wind turbine and flanged diffusers.

This work is restricted to uniform, steady and parallel flow conditions. Furthermore, emphasis is put on measurements in controlled conditions. Focus was to design and fabricate a model wind turbine, and use it to carry out an experiment in order to evaluate and compare the performance characteristic of global parameters of the wind turbine with diffusers of different dimensional configurations, tested at a small sub-sonic wind tunnel. The scope also includes measurement of electrical power output along the control axis of the hollow-structure and wake velocity at the flange of the diffuser for feature simulation analysis. Areas not covered in this work include wake analysis, vortex expansion, flow pattern, rotor-tower interaction.

2 | Materials and Methods

2.1 | Materials for the Flanged-Diffuser Development

These were designed and fabricated from metal sheet (1.0 mm gauge); Iron rods (10 mm)/ binding wires; M10 bolt and nut/washers; 4 sets of metal Iron rod of 1000 mm high with adjustable groove etc. For this work, the five flanged-diffuser inlet-to-outlet diameter ratios, Ai/Ao used were 0.50, 0.57, 0.66, 0.72, and 0.80. This is within the tolerance limit (0.50 to 0.80 specified by Lipian et al. [16]. The Airfoil NACA 4415 was used in this work. The airfoil model was made from a polyethylene material with a chord length of 165.0 mm and with a span of 10.0 mm.

2.2 | Methods for Developing the Wind Turbine with Flanged Diffuser

A comprehensive review of literature of past researchers work on wind turbine with diffuser was thoroughly examined. A small model wind turbine coupled with a dynamo and flanged diffusers was developed. The NACA 4415 airfoil cross-section was adopted for the blades which were made of high-density polyethylene materials which were machined to the blade geometry.

The experiments were conducted using analogue PLINT & Partners Subsonic wind tunnel machine (see, *Fig. 1*), carried out at the exit area of the wind tunnel, with a measurements section of 0.487 m by 0.487 m (width) × 0.95 m (height); center-line (reference point) from ground level, with a maximum wind velocity of 30 m/s. In this study, the wind turbine and the flanged diffuser is located 700 mm downstream of the wind tunnel exit. The wind tunnel exit diameter was taken as a reference point during

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the design stages, such that the diffuser inlet diameter was less than the tunnel exit geometry while the turbine rotor and swept area fed into the diffuser inlet area.

Fig. 1. Analogue PLINT & partners subsonic wind tunnel machine.

The wind turbine was three blade rotor with a diameter of 390.8 mm. The blade was designed with the aid of a design theory by Schubel and Crossley [15]. Other instruments/equipment include: a digital TSI AINOR Airflow hot wire anemometer which has a measuring range of 0 to 30 m/s, sensitivity of 0.01 m/s and accuracy of ±3%; a compact Digital Stroboscope with a range of 1 to 30,000 rpm and a sensitivity of 0.01 rpm; a length of thread, an assortment of masses in grams, mass hanger, a weighing balance, and stop watch (all for measuring torque); a 6-Watt, 4.6-V lamp; a voltmeter and connecting cables.

2.2.1 | Design of wind turbine and flanged diffuser

In order to optimize better output performance, several features including the geometry of the diffuser and flange was attached to it, the wind turbine (shaft bearing, rotor blades, etc) were designed and constructed.

2.2.2 | Design consideration

It has been confirmed that maximum performance can be achieved when the ratio of the diffuser length to inlet diameter L/D, and flange width to inlet diameter (H/D) is between (0.25-0.75 m); as in the case of this experiment [16]. The design constraints included: the use of Kano mean wind speed from 3.0 m/s to 5.0 m/s at 10-m height and extended to 7.0 m/s for extrapolated wind speeds of up to 60-m height for the same city [17], the use of flanged diffusers of inlet to outlet diameter ratios of 0.50, 0.57, 0.66, 0.72, and 0.80.

2.2.3 | Flange diffuser fabrication

The three main features such as: the diffuser inlet; the outlet portion of a diffuser; and the flange which is an extrusion of the diffuser located at the back outer edge of the diffuser were considered separately during design in order to direct sufficient amount of air velocity into the diffuser. Sketch of a typical diffuser with flange is shown in *Fig. 2*.

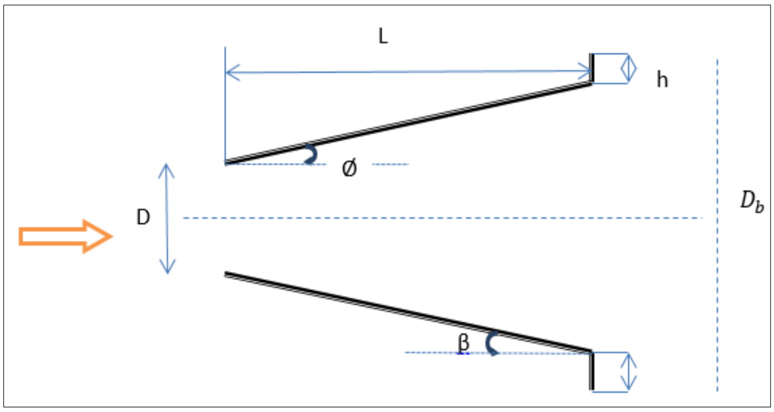

Fig. 2. **A sketch of a diffuser with flange.**

2.2.4 | Selection of shaft

The shaft was selected based on twisting moment or torque only. On the other hand, the torque transmitted by the shaft was calculated using *Eq. (1)* while the diameter was calculated using *Eq. (2)*.

$$T = WR. \quad (1)$$

$$T = \frac{\pi}{16} x \tau x d^3. \quad (2)$$

Considering a maximum permissible working torsional shear stress, (τ) = 42 MPa = 42 N/mm^2, Shaft + blade, W_R = 0.1219 kg; Mass of bearing = 0.10562 kg.

Total weight of bearing, W_T = m x g + FS = 0.10562 x 9.81+1.5 = 2.536 N.

Where, W is the actual weight exerted on the system, R is the radius about which the weight (needed to completely stop the shaft from turning) was suspended. The bearings were selected based on ability to withstand momentary shock loads, with accuracy of shaft alignment.

2.2.5 | Design of rotor blade

The three-bladed rotor model were made from High density thermoplastic (polyethylene) material of petroleum product for the purpose of high impact/good tensile strength; which can withstand temperatures up to (120℃/248°F for short periods, 110℃/230°F continuously); as well as reducing industrial noise. The blade tip clearance ratio was less than the inlet diameter of the diffuser. The Airfoil NACA 4415 was adopted because its profile was easily accessible, with a chord length of 165.0mm and spans 10.0mm, tapered at 66.0mm. The cross section was drawn to scale on a graph paper and then machined with the designed dimensions. The rotor assembly was mounted on a stand with respect to the required height. The stand was designed with a round heavy-hollow pipe cast steel in order to withstand axial load without buckling.

2.2.6 | Experimental procedures

The rotor, shaft, and the dynamo were supported by a single stand with a two-ball bearing system mounted on it, to allow for a low frictional rotation of the shaft. The arrangement was then placed at the exit of the wind tunnel to receive the incoming wind. The instruments were positioned at the right places for measurements, and the wind tunnel was powered and the air through it was varied by adjusting the screw to open the butterfly valve at the entrance. At each setting speed, the on-coming wind speed, the wind speed just behind the rotor, the wind speed around the flange of the diffuser, the rotor angular speed, the prevailing temperature, and the torque produced were measured and recorded. The experiment was conducted with and without flanged diffusers for nine different variations of wind speed. The results obtained were used to gather an array of output that determined the significance of each parameter on the output. Finally, the stoppage turning point of the rotor was determined through

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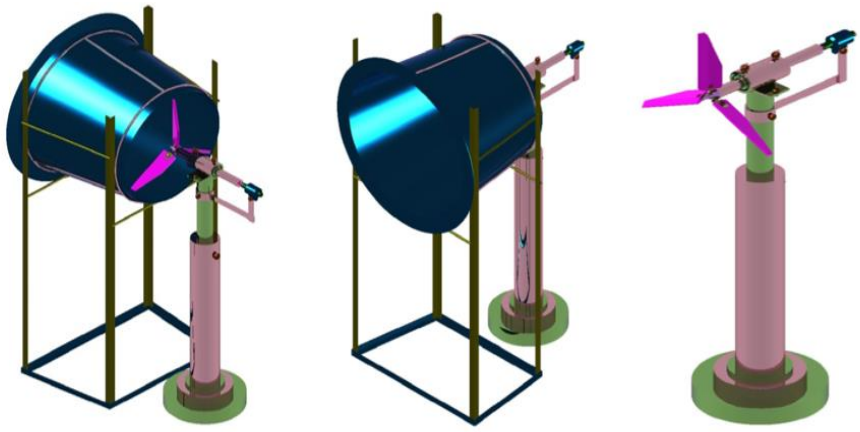
the suspension of masses via a thread tight process at the hub of the rotating shaft axle. This placement of the mass over the rotor was used to calculate the torque transmitted by the turbine system. The wind turbine rotor model assembly is as shown in *Fig. 3*.



a b c

Fig. 3. Wind turbine rotor model assembly.

2.2.7 | Calculated performance parameters

The system mechanical shaft power becomes

$$P_s = \frac{2\pi NT}{60}. \tag{3}$$

From the moving fluid mass of *Eq. (3)*, the wind power is calculated using the expression in *Eq. (4)*:

$$P_w = \frac{1}{2}\rho AV^3. \tag{4}$$

The density of dry air at low pressure (1 atm) at the corresponding temperature in each wind velocities was derived from Steam Table for the computation of the extracted wind power by the rotor, using *Eq. (5)* below for the swept area, A:

$$A = \pi r^2. \tag{5}$$

The power coefficient was computed as thus [8],

$$C_P = \frac{\left(1 + \frac{V_w}{V}\right)\left(1 - \left(\frac{V_w}{V}\right)^2\right)}{2}. \tag{6}$$

Also, the turbine TSR, λ is calculated as

$$\lambda = \frac{r\omega}{U_o}. \tag{7}$$

But

$$\omega = \frac{2\pi n}{60}. \tag{8}$$

The power output extracted by the wind turbine without the flanged diffuser can be expressed as

$$P = \frac{1}{2}C_P\, \rho AU^3. \tag{9}$$

Eq. (1) to *(9)*, were then used to compute the parameters of the wind turbine with flanged diffuser.

3 | Results and Discussion

The results obtained from experimental and other calculations carried out in this study are presented and discussed in this section.

3.1 | Data Presentation

Generally, two methods are available to analyze the performance of wind turbines namely CFD, and Wind Tunnel Experiments (WTE). However, both methods are employed in some cases [8]. In this study, WTE was used. This section shows the results obtained with and without the flanged diffuser and the analysis of power output through measured and calculated values, using graphical plots. Performance of the wind turbine parameters without flanged diffuser are presented in *Table 1*.

Table 1. Measured data obtained without flanged diffuser (cut-in speed = 2.82m/s).

S/N	Wind Speed (m/s)	Electrical Power (W)	Rotational Speed (rpm)	V_w (m/s)	Mass (g)	Temperature (°C)
1	3.0	0.096	2	1.99	20	31.0
2	3.5	0.122	5	2.29	30	31.0
3	4.0	0.154	25	2.66	60	31.1
4	4.5	0.172	50	2.75	80	31.1
5	5.0	0.191	97	2.81	130	31.1
6	5.5	1.153	130	2.89	210	29.6
7	6.0	1.211	152	2.95	290	29.7
8	6.5	1.340	170	3.00	340	29.6
9	7.0	1.453	193	3.10	410	29.7

3.2 | Tip-Speed Ratio

This is the ratio of the angular speed of the rotor blades to the mean wind speed; the rotors of a wind turbine (especially used for electricity generation) need to spin fast in order to capture the wind for more energy conversion; for a three-bladed rotor, this ratio is usually greater than or equal to 1. *Fig. 4* shows the TSR of the wind turbine with and without the flanged diffuser.

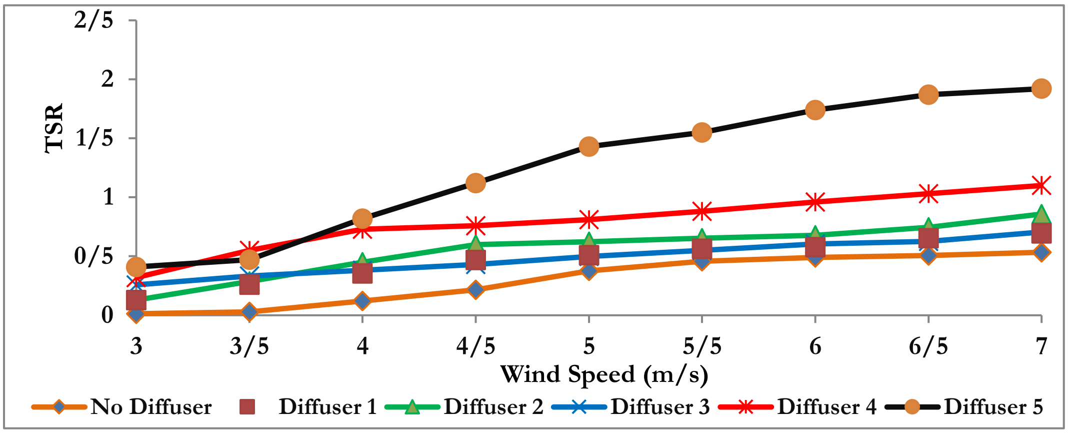


Fig. 4. TSR against wind speed for each diffuser.

This result shows improvements in the TSR with the use of the flanged diffusers; up to a wind speed of 6 m/s the TSR for the turbine without diffuser was less than 1, but with the diffusers this improved greatly, with the turbine with diffusers 4 and 5 (inlet-to outlet diameter ratios, Di/Do of 0.72 and 0.80, respectively) reaching a TSR greater than 1 even at cut-in speeds of about 3.5 m/s. The mean increments were a minimum of about 45% with the smallest diffuser (Di/Do = 0.5) and a maximum of about 80% with the largest diffuser. However, the later value is not necessarily an indicator of good performance as the rather high value may cause large amount of wind to pass through the rotors without commensurate yield in power. This is buttressed in the analysis for the power output and efficiencies shown later in this work.

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3.3 | Rotational Speed

Fig. 5 shows the results for the rotational speed obtained with and without the use of the flanged diffusers. Also, *Fig. 6* represent the results for the torque obtained with and without the use of the flanged diffusers at wind speeds ranging from 3-7 m/s.

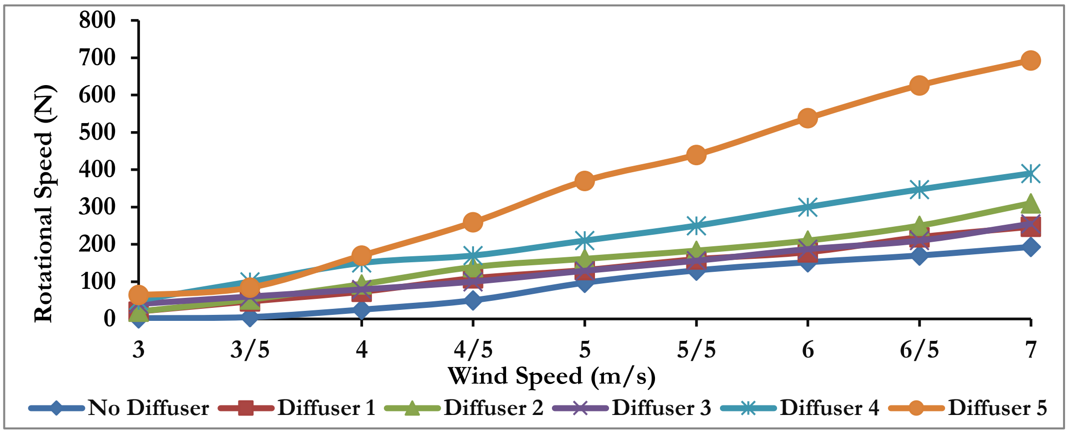

Fig. 5. Variation of rotational speed with wind speed across the diffusers.

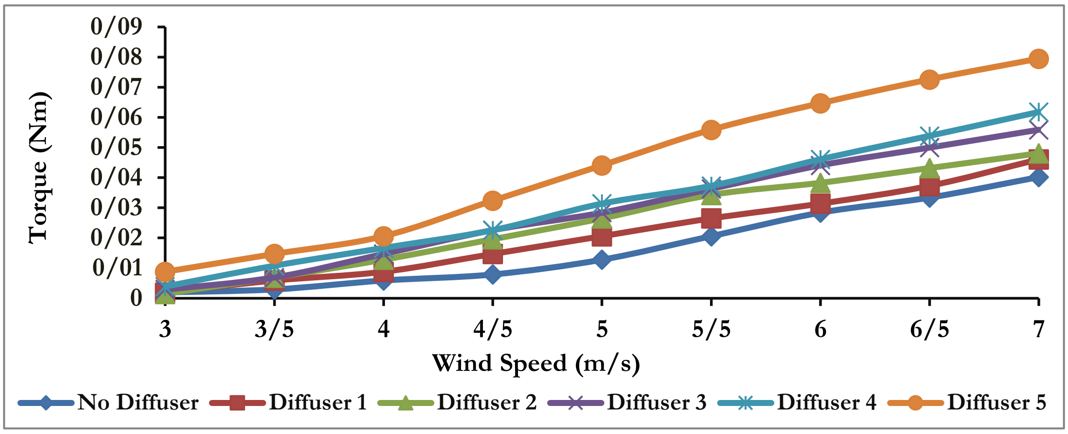

Fig. 6. Variation of torque with wind speed for each diffuser.

However, the more appreciable mean increments in torque were achieved with diffuser Di/Do ratios of and 0.60, 0.70 and 0.80 with mean increments of 46, 52 and 66%, respectively. Even at a modest wind speed of about 4.5 m/s the increments were as much as 65, 65 and 76% respectively for the later three diffusers. The results in *Fig. 6* shows that though the torque increased with increasing diffuser Di/Do ratio the lower ratios of 0.50, and 0.60, made only modest impacts on the realizable increments in torque with a mean maximum increment of about 24 and 33% respectively.

3.4 | Output Power

Results of output power obtained from the turbine with and without the flanged diffuser is shown in *Fig. 7*. The results of each model of the diffuser showed an increase in power output with wind speed which also indicated that, a wind turbine with flanged diffusers produced more power than the one without diffuser. The power increased from a wind speed of 3 m/s to a maximum wind speed of 5 m/s and declined to a minimum wind speed value of 7 m/s. The mean value of increment indicated that the increments are independent on the changing geometry (Di/Do ratio) of the diffusers, as mean increment across the speed range used for all five diffusers was between 52% and 57%. The variation was not in increasing order of the ratio, as the greater value was obtained with the second largest diffuser (Di/Do = 0.70) and the least value with the largest diffuser (Di/Do = 0.80). The first three diffusers achieved near identical mean increments of 55%. The results also showed that using flange diffuser improved the power output up to a moderate speed of 5 m/s; beyond this, the large increment in the TSR caused the wind turbine with diffuser to extract less power from the rapidly flowing wind speed. This is buttressed by the decline in the power output beyond 5 m/s wind speed.

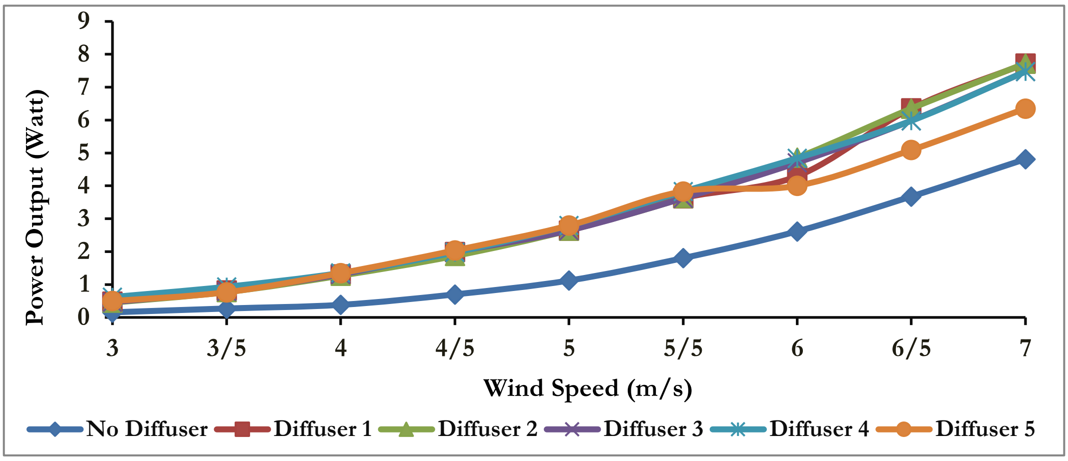

Fig. 7. Power output obtained for each diffuser.

3.5 | Power Coefficient (Cp)

The variation in power coefficient with changing wind velocity is shown in the performance curve of *Fig. 8*. The results indicated that wind turbine with flanged diffuser significantly enhanced the performance output compared to wind turbines operating without diffuser. The Figure shows that wind turbine with no diffuser had an efficiency of 0.09 within wind speed of 3.0 to 4.0 m/s, but increased to a maximum power coefficient of 0.22 at a wind speed of 7.0 m/s.

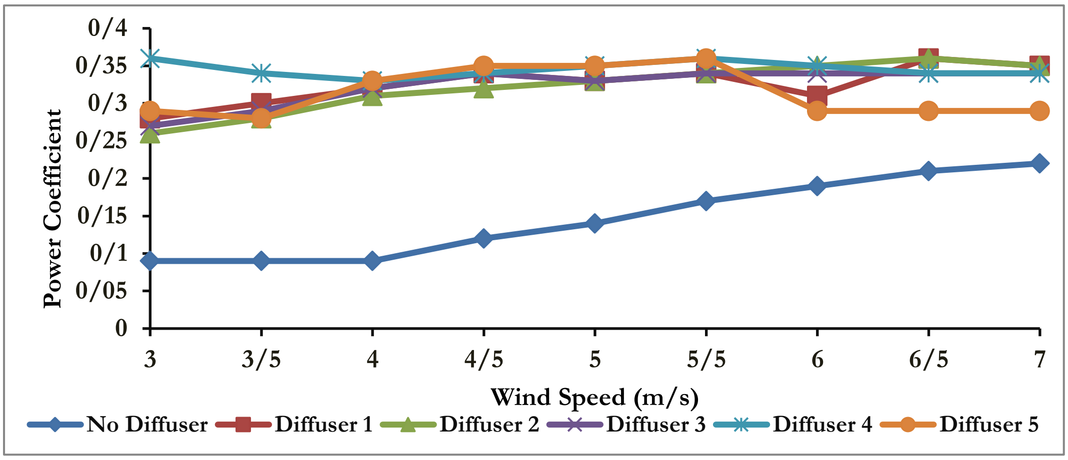

Fig. 8. Power coefficient (Cp) obtained for each diffuser.

However, there was an improvement in the efficiency of power extraction when the diffuser was introduced; the Cp increased from 0.28 to 0.35 across the speed range with the smallest diffuser; in the case of the largest diffuser this was from 0.29 to 0.36 at about 5.5 m/s wind speed and then remains constant up to the maximum wind speed of 7 m/s. This pattern is repeated for all the remaining diffusers, i.e., with the optimum efficiency occurring at about 5.5 m/s wind speed.

Comparatively, because the Cp is a function of the output power, the increments (from when the turbine is without the diffuser to when operating with the diffuser) are the same as described for the output power.

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3.6 | Velocities at the Wake and at the Periphery of the Flange of the Diffuser

In addition to using the velocities at the wake (just behind the rotor) for the computation of the Cp, together with the velocities at the periphery of the flange on the diffusers, provide basic inputs for use for future work on simulation with a CFD software for the purpose of comparison with the results of this experimental work as well as for prediction with different rotor and flanged diffuser sizes and for revealing weak areas in their wakes with a view to improving the diffuser designs. In this way too, practical real-life wind turbine (with and without flanged diffuser) performance can be predicted. The predicted results from this simulation will of course need validation by results of practical (field) measurements.

4 | Conclusion

The performance characteristics of a Horizontal Axis Wind Turbine (HAWT), with and without flanged diffusers, using WTE were studied. Measurements of the global parameters (power coefficient, power output, torque, rotational speed and TSR) with and without the flanged diffusers were made at different wind velocities. The results showed different effect each diffuser had on the power output based on the geometry of the diffuser. Though the wind speed simulated was for low (whose mean wind speed at 10.0m height is between 4.0 and 5.0 m/s), the speed range was extended up to 7.0 m/s, being about the extrapolated wind speed for the same low wind speed Region at a height of about 70 m.

The results show mean increments in the TSRs of minimum of about 45% with the smallest diffuser and a maximum of about 80% with the largest diffuser. Because the TSR is a function of the rotational speed, the results of the two are identical in the increments obtained with the use of the diffusers. As for the torque, only modest increments were obtained for the first two diffusers, with a maximum increment of about 33%. However, even at a modest wind speed of about 4.5 m/s the increments were as much as 65, 65 and 76% respectively for the later three diffusers. Lastly, both the power output and the power coefficient exhibited similar characteristics, as they both increased (with the diffuser on the turbine compared to without the diffuser) from as little a speed as 3 m/s to a maximum value of about 5m/s wind speed and thereafter declined to a minimum value of 7m/s wind speed. The mean values of increment revealed that the increments are independent on the changing geometry (Di/Do ratio) of the diffusers, as mean increment across the speed range used for all five diffusers was between 52 and 57%. The variation was not in increasing order of the ratio, as the greater value was obtained with the second largest diffuser (Di/Do = 0.70) and the least value with the largest diffuser (Di/Do = 0.80). The first three diffusers achieved near identical increments of 55%. The results also indicated that using flanged diffuser improved the power output and hence, the power coefficient up to only a moderate speed of 5 m/s. Beyond this, the large increment in the TSR caused the wind turbine with diffuser to extract less power from the rapidly flowing wind speed. This is buttressed by the decline in the power output beyond 5 m/s wind speed. Based on the analysis done so far in this investigation, the following are recommended for future studies:

I. Since improvement in power production at zones described by low wind speed can be achieved, the use of flanged diffusers may be implemented on stand-alone wind generators for small-scale businesses and rural communities in the area with low wind speed terrain, etc.
II. In this work, the lengths of the diffusers were kept constant; further studies may entail variation in both lengths and the inlet-to-outlet ratios.
III. The flanged diffuser optimization performance may be carried out with CFD in order to validate results with this experimental work, as well as reveal weak areas in the wake such as separation and turbulent flow, with a view to modifying the diffuser to mitigate these effects.
IV. A real life wind turbine may be built and tested with a flanged diffuser since the results from this work, though experimental, appears to be more ideal.

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Appendix

Table 1. Overall summary of both measured and calculated parameters without flanged diffuser.

	Measured Values				Calculated Values				
	Wind Speed (m/s)	Electrical Power (W)	Rotational Speed (rpm)	Temp. (°C)	Torque (Nm)	Mech. Power	TSR	Power Coefficient (C_P)	Power output(W)
1	3.0	0.096	2	31.0	0.00196	0.00041	0.013	0.09	0.1556
2	3.5	0.122	5	31.0	0.00294	0.0015	0.028	0.09	0.2716
3	4.0	0.154	25	31.1	0.0059	0.0154	0.121	0.09	0.3829
4	4.5	0.172	50	31.1	0.0079	0.0411	0.215	0.12	0.7006
5	5.0	0.191	97	31.1	0.0128	0.1296	0.376	0.14	1.1212
6	5.5	1.153	130	29.6	0.0206	0.2804	0.458	0.17	1.8037
7	6.0	1.211	152	29.7	0.0284	0.4529	0.491	0.19	2.6180
8	6.5	1.340	170	29.6	0.0334	0.5939	0.507	0.21	3.6778
9	7.0	1.453	193	29.7	0.0402	0.8130	0.534	0.22	4.8137