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Optimization of Diffuser Type Wind Lens Geometry

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Abstract

Conventional wind turbines are generally inefficient due to various losses it encounters. Losses such as tip vortex loss, noise. Furthermore, if more wind energy is converted by blades, it would result in high pressure drop in the wake of the blade, which will lead to back flow of the air.

The aim of this research is to increase the energy production of small wind turbines by increasing wind velocity at the turbine blades through the design of a shroud attachment (wind lens). The design process involves the analysis of various computer aided design (CAD) nozzle/diffuser shroud geometries. Computational fluid dynamic (CFD) modelling is used to analyse the effect of shroud features on velocity. The resulting design locally increases velocity by a factor of 1.3-1.4, and subsequent energy yield by a factor of 3-3.5 when compared to the performance of an un-shrouded turbine.

Keywords— *Wind lens, D.O.E., Computational fluid dynamics, Renewable energy, CAD, vortex*

I. Introduction

An alternative, wind turbine technology may provide electricity in these rural locations. In particular, small wind turbines are an attractive option for developing markets that currently lack electricity or are energy deficient. Small wind turbines can operate for extended periods without attention; with only a few moving parts, these systems have very low maintenance requirements compared to other energy options

[4] Kishore, Ravi et al. said that small wind turbines are not difficult to manufacture. In this respect, local manufacturing is often a suitable option for developing countries that could, in turn, stimulate local economic development and lower production costs. Wind systems replace existing household expenditures for kerosene, candles and dry-cell batteries. Lastly, wind systems require little to no water to operate and do not contribute greenhouse gases or other toxins to the environment.

Wind Tunnel Tests on a Wind Turbine with Contractor and Diffuser Arrangement :-

Another system for increasing the wind speed through a wind turbine is a symmetrical nozzle and diffuser. Nine different models were tested in which the main parameters investigated were the ratio of inlet to turbine diameters, the ratio of outlet to turbine diameters, and the length of transition from inlet to contraction and outlet [3] Fletcher, J. et al. explained that through the use of different geometric 7 variations and CFD modelling, it was determined that a mirrored system where the inlet matched the outlet would produce the best results. In order to best analyse the data from modelling and testing, the energy in the airflow and the ratio between energy at the inlet and energy at the turbine blades was calculated by,

$$W = 0.5\rho A U^3$$

$$\frac{W_2}{W_1} = \frac{\rho_2 A_2 U_2^3}{\rho_1 A_1 U_1^3} = \left(\frac{U_2}{U_1}\right)^2$$

Where,
W is the wind energy available
 is the density of air
A is the cross-sectional area
U is the velocity of the air

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Along with their design, data from the modelling and wind tunnel testing is provided. This data shows the differences in power output from the turbine when provided with a constant wind speed.

CFD Analysis for Optimization of Diffuser for a Micro Wind Turbine:-

[5] Kale Sandip A et al. concluded that in the hope of lowering the pressure at the outlet of the diffuser even more, the effect of a flange around the outlet and its angle has been researched. Three different setups were tested. When the diffuser is vertically flanged, wind speeds are increased by 34.28% and when the flange is angled 10°, speeds are increased by 40.3%. Through a fairly simple test, it was proven that by angling the flange, speeds are significantly affected. a diffuser without a flange, a diffuser with a vertical flange, and a diffuser angled back 10° From the tests, it was concluded that while the diffuser without a flange increases wind speeds through the turbine by 18.57%, it does not compare with the effects of adding a flange.

II. .DESIGN OF BRIM AND DUCT

A. All Selection of a Diffuser-Type Structure as the Basic Form

In a research done by [2] Ohya Yuji et al. explained two types of hollow-structure models - a nozzle and a diffuser, were studied and tested. The distributions of wind velocity U and static pressure p along the central axis of the hollow-structure model were measured and the experiments revealed that a diffuser-shaped structure can accelerate the wind at the entrance of the duct.

If a long type diffuser is used, the wind speed is accelerated further near the entrance of the diffuser. However, such a long heavy structure is not preferable in practical sense. Then [2] Ohya Yuji et al. added a ring-type plate, called “brim”, to the exit periphery of a short diffuser. The plate forms vortices behind it which results in generation of a low-pressure region behind the diffuser. Consequently, the wind flows into a low-pressure region and the wind velocity is further accelerated near the entrance of the diffuser. A shrouded wind turbine equipped with a brimmed diffuser came into existence in this way and was termed as the “wind-lens turbine”.

Also considering other parameters, [2] Ohya Yuji et al. examined the diffuser opening angle, the hub ratio, and the centre-body length. Then the optimal shape of a brimmed diffuser was found giving a remarkable increase in the output power coefficient (Cw =P/0.5ρAU3, P: output power, A: swept area of turbine blades) of approximately 4–5 times that of a conventional wind turbine in a field experiment. The present wind- lens turbine is explained using a simple theory given by Inoue the pressure discovery coefficient of the diffuser shroud and the base pressure behind it are the two factors that decide output performance of turbine The key features of this wind-lens turbine equipped with a diffuser shroud are as follows:

(1) Four-fivefold increase in power output compared to conventional wind turbines due to concentration of the wind energy (“wind-lens” technology).

(2) Brim-based yaw control: The brim at the exit of the diffuser makes wind turbines equipped with a brimmed diffuser rotate following the change in the wind direction, like a weathercock. Therefore, the wind turbine automatically turns to face the wind.

(3) Significant reduction in wind turbine noise: The aerofoil chosen for the turbine blade gives the best performance in a low-tip speed ratio range. Since the vortices generated at the tip of blades are considerably suppressed through the interference with the boundary layer within the diffuser shroud, the aerodynamic noise is reduced significantly.

(4) Improved safety: The wind turbine is shrouded by a structure making it safe against damage from broken blades even at high rotating speed.

(5) As for demerits, there is increase in structural weight and thrust load due to wind on the wind turbine

He created 4 diffuser models namely, Aii, Bii, Cii and Sii. Table shows the length ratios Lt /D and the area ratios μ of (exit area) / (throat area) for each diffuser model. All diffuser types show almost the same Lt /D, but show different area ratio μ. For the S- type diffuser, it has a straight sectional shape such as the 500 W prototype.

For the practical application we have developed a compact-type brimmed diffuser. For the size of the brimmed diffuser in the present experiment, the throat diameter D is 310 mm and the rotor diameter is 304.8 mm. The research done by [2] Ohya et al. concluded that the C-ii type brimmed diffuser gave the best outcomes, but, due to constraints of manufacturing and limited resources available to us, we created a converging- diverging nozzle that would replicate the geometry of C-ii. Energy(P) is carried by moving air

$$P = 0.5\rho AV^3$$

There exists a physical limit to the amount of energy that can be extracted, which isn't dependent on the design. The quantity of energy harnessed is a function of the reduction in air speed over the turbine. 100% extraction is not possible as it implies zero final velocity and therefore zero flow. Since, zero flow condition cannot be met hence all the kinetic energy of the wind is not utilized. From this principle it was concluded that wind turbine efficiency cannot exceed 59.3%. This parameter is commonly known as the power coefficient Cp, where max Cp = 0.593 referred to as the Betz limit. In Betz theory it is assumed that wind velocity is constant linear velocity. Therefore, any rotational forces such as wake rotation, tip losses or turbulence caused by drag will cause further reduction in efficiency. Efficiency losses can be avoided by to:

- Avoid high tip speed ratios which increase wake rotation.
- Selecting aerofoils with high lift to drag ratio.
- Specialized tip geometries.
- Practical Efficiency
- In actuality rotor designs suffer from the accumulation of minor losses in form of:
- Tip losses
- Wake effects
- Drive train efficiency losses
- Blade shape simplification losses

III. Design of Experiment

A three factors two-level Design of Experiments (DOE) approach was used to analyse sixteen different scaled shroud geometries and the impact that selected factors had on the performance of the design. This was the chosen methodology because it optimizes the design process, reduced late engineering design changes, and reduced product material and labour complexity.

The primary analysis included three factors: flange angle, flange length and diffuser angle. The factors were measured as per steps provided in available literature. In this case, wind velocity at the location of the turbine blades was used as the output for each iteration.

Isolated parameters	Maximum value	Minimum value
Flange angle	90°	65°
Flange length (m)	0.1	0.05
Diffuser angle	14°	5°

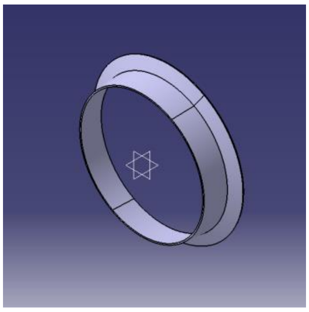
1. Geometries for CAD models:

General common dimensions used in cad models are based on [2] ohya's cii model are
D (diameter of wind lens at turbine blade tip) = 1 meter
Lt (total length of wind lens) = 0.221 meter
Models created through DOE are

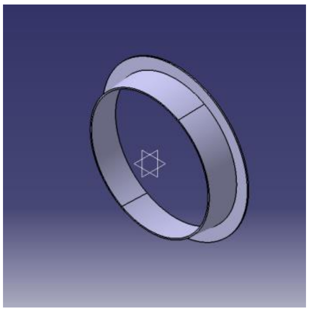
1) With Diffuser angle = 5° flange length = 0.05 m Flange angle = 65°

2) With Diffuser angle = 5° flange length = 0.05 m
Flange angle = 90°

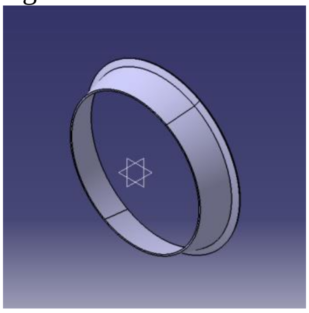
3) With Diffuser angle = 5° flange length = 0.1 m
Flange angle = 65°



4) With Diffuser angle = 5° flange length = 0.1 m
Flange angle = 90°

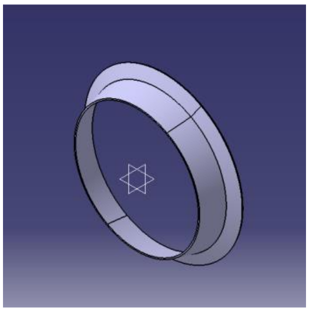


5) With Diffuser angle = 14° flange length = 0.05 m Flange angle = 65°

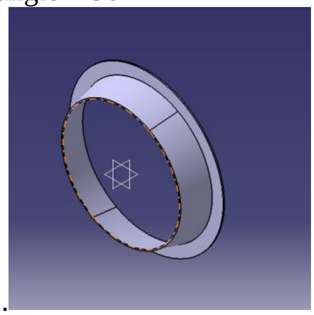


6) With Diffuser angle = 14° flange length = 0.05 m Flange angle = 90°

7) With Diffuser angle = 14° flange length = 0.1 m
Flange angle = 65°



8) With Diffuser angle = 14° flange length = 0.1 m Flange angle = 90°



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IV. RESULTS AND CONCLUSION

We have tested eight CAD geometries in ansys fluent version 16.0 , according to the references available the assume boundary condition where inlet velocity is equal to 6 m/s.

The velocity contours obtained in a plane 0.1105 m from inlet for CAD models are as follows:

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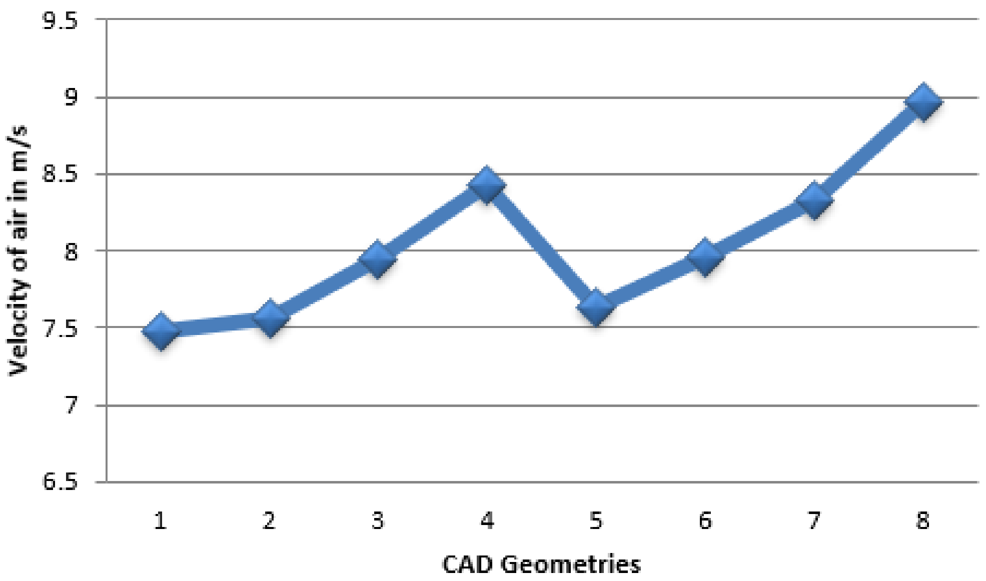

Figure 1: Result graph of mentioned DOE

From above graph it can be concluded that:

1. By keeping diffuser angle and flange length constant, when flange angle is increased to 90° velocity of air is increased (refer velocities of model no. 1 and model no. 2)
2. By keeping diffuser angle and flange angle constant when flange length is increased to 0.1m there is increase in velocity. (refer velocities of model no. 1 vs model no. 3 and model no. 2 vs model no. 4)
3. By keeping flange length and flange angle constant when diffuser angle is increased to 14° there is increase in velocity. (refer velocities of model no. 1 vs model no. 5, model no. 2 vs model no. 6, model no. 3 vs model no. 7, model no. 4 vs model no. 8)
4. From above three statements it can be interpreted that at diffuser angle = 14°, flange length = 0.1 m, flange angle = 90° are optimum parameters.

Below are the results of eighth CAD model, whose velocity in the mentioned plane was 8.97 m/s (maximum)

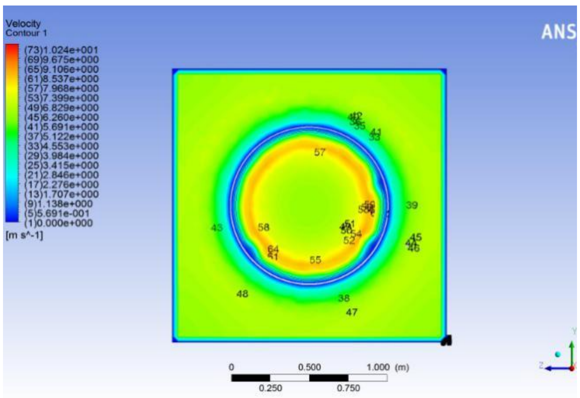

Figure 2: Velocity contours

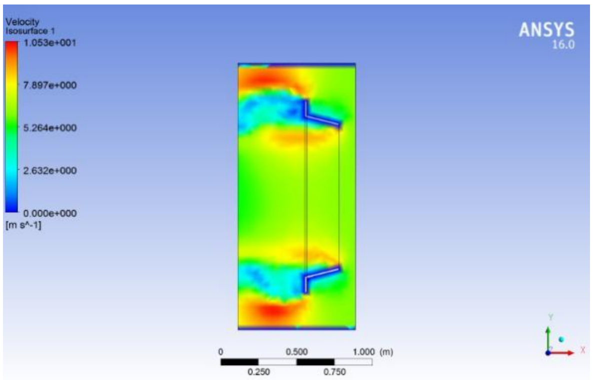

Figure 3: Velocity contour in a plane perpendicular to geometry

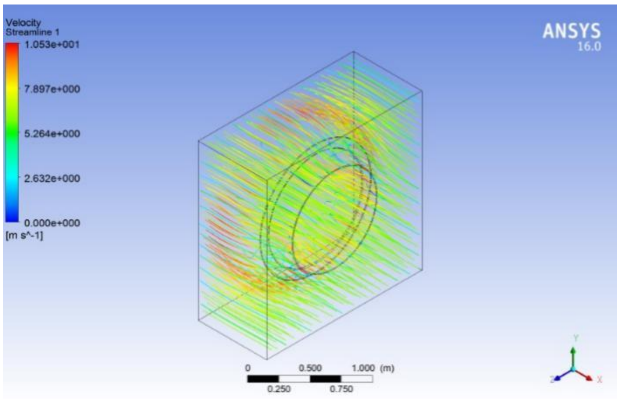

Figure 4: Streamlines showing particle flow (vortices and whirls)

According to results obtained from analysis of various CAD models of given DOE, the maximum velocity was obtained in model number eight (With Diffuser angle = 14° flange length = 0.1 m Flange angle = 90°) is 8.97 m/s.

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