99. Modeling and Simulation of Diffuser Augmented Wind Turbine

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Abstract

In this work the diffuser augmented wind turbines have been studied to increase the mass flow rate through the rotor which results in improved energy extraction from the wind. The pressure drop is caused by a flange at the exit of diffuser. For analyzing the flow behaviour of bare and flange type diffuser ANSYS Fluent 12.0 is used. The study showed that power can be augmented using flange type diffuser on simple horizontal axis wind turbine. Power coefficient increases due to addition of flange type diffuser and wind velocity also increases at rotor of the turbine. Further this study also confirms the experimental work of Yuji Ohya a Professor at Kyushu University Japan.

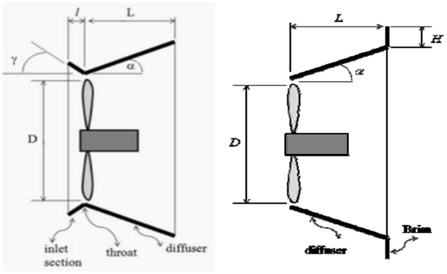
Keywords: *diffuser augmented wind turbine, flow behaviour, flange type diffuser, CFD, Power coefficient*

1. Introduction

With the growing requirement of sustainable energy sources and growing crisis of climate change and clean environments in the whole world therefore the development of clean and sustainable energy gradually become more and more important research subjects. Wind energy is one of important sustainable energy source. Researchers around the world have been making many efforts to develop advanced wind power systems. Wind turbine is one way to extract the power from the wind. The power output is directly proportional to cube of velocity so that small changes in velocity can significantly increase.

Therefore the development of an effective wind acceleration system by placing the turbine rotor inside a shroud has attracted much attention of researchers. This kind of wind turbine is often referred to as diffuser augmented wind turbine (DAWT) [1]. The research on Diffuser augmented wind turbines has been shown by many studies can significantly increase the power output. The present study on the development of a wind power system with high output aims at determining how to collect the wind energy efficiently and what kind of wind turbine can generate energy efficiently from wind. For this purpose we have modelled a diffuser type shroud in Gambit software that is capable of collecting and accelerating the approaching wind. Furthermore we placed a wind turbine inside the diffuser shroud equipped with a flange and evaluated the power output generated. As a result the shrouded wind turbine equipped with a flanged diffuser demonstrated power augmentation for a given turbine diameter and wind speed by a factor of about 4-5 compared to a standard micro wind turbine [2]. Simple diffuser consists of three sections (Fig. 1a): inlet section, turbine section or throat and diffusing outlet section. Despite the importance of diffuser geometrical parameters there is limited experimental study comparing the performance of bare turbine with shrouded turbine under controlled flow condition and rotor speed [3]. Diffuser causes the flow to accelerate because the flange on diffuser causes the drop in the pressure at the exit of Diffuser. Vacuum causes flow to accelerate and increase in mass flow and velocity which eventually lead to increase in power co- efficient. The ANSYS Fluent 12.0 and Gambit Softwares have been used for simulation and modelling purpose respectively. The diffuser design parameter play very important role in increasing the mass flow and wind velocity. There are four parameters which can effect the power output which is length, angle of diffuser, and flange height. ANSYS Fluent have been for simulation purpose in this study and k-w and k-ε model have been used for obtaining the results the k-ε and k-w model are best methods to apply from design analysis.

Subject to axial and non-axial inflow conditions



(a) (b)

Fig. 1. Simple shroud designs for wind turbine: (a) nozzle-diffuser and (b) diffuser-Brim shroud [3].

2. Modeling and Simulation

To create the geometry of the DAWT we have used the GAMBIT 2.4.6 software. Our model design starts with the designing of hub, designing of blades, designing of diffuser and meshing of geometry.

2.1 Designing of Hub

The diameter of hub we have taken is 62mm and length is 95mm.

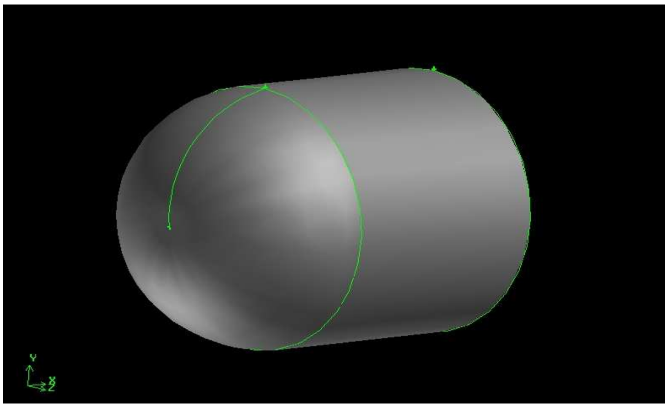


Fig. 2. Shaded view of Design of hub

2.2 Designing of blades

The span of blades is 64mm, chord is 25mm, the thickness of blades is 2.5mm and number of blades are 3.

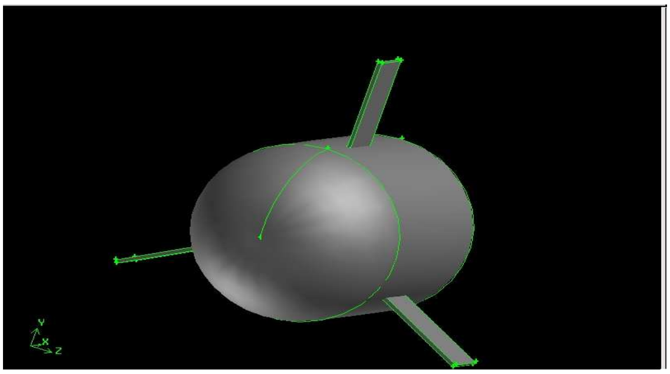


Fig. 3. Shaded view of design of blades

2.3 Designing of Diffuser

The rotor diameter (D) is 190mm, Outlet diameter is 240.73mm, Length (L) is 120mm and the Expansion angle (α) is 5°.

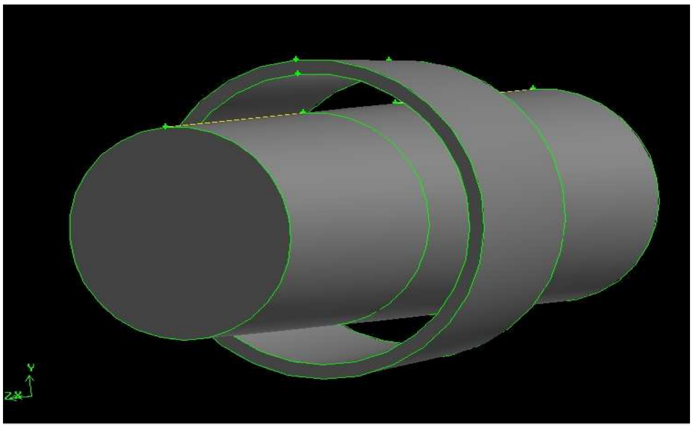


Fig. 4. Shaded view of diffuser around domain

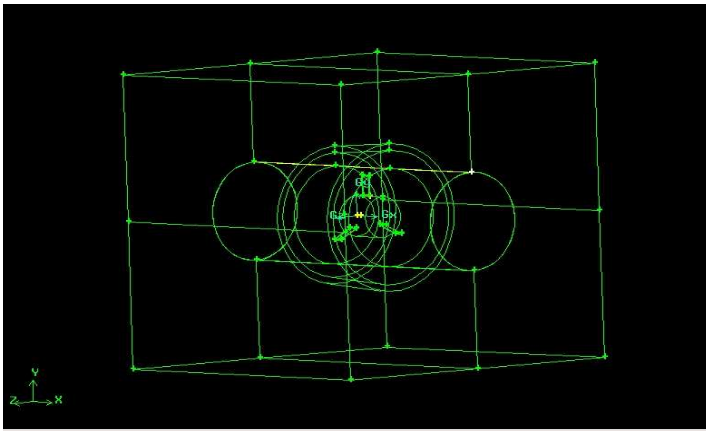


Fig. 5. Shows creation of volume

2.4 Meshing of Geometry

The last step in designing has been performed and now we will try to mesh our geometry. For that we will go into meshing option and fac mesh option. We will quad+tri type mesh. After completing the meshing we will apply boundary conditions to our geometry.

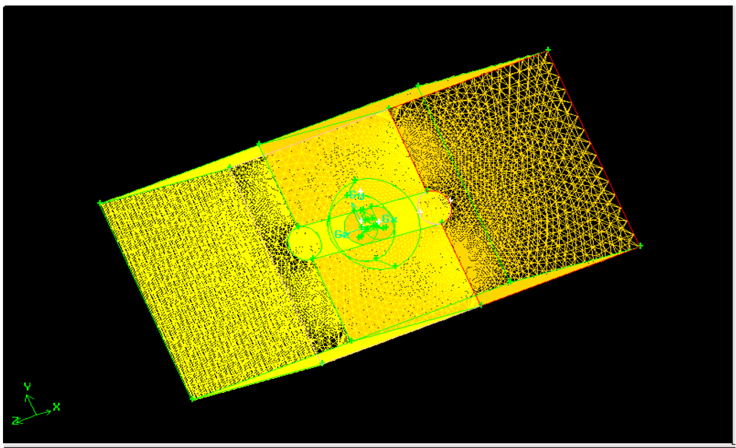


Fig. 6. Shows complete mesh

For simulation purpose we shall use the computational Fluid dynamics program "FLUENT" which is part of ANSYS 12.0 software program. We have used the 3D Simulations.

3. Results and Discussion

From our simulations we now summarize our findings. We determined that power output can be increased to bare wind turbine by addition of diffuser. In this attempt the k-omega model was used and simplec 2nd oder equations were applied. In solution control we reduced parameter of pressure from 0.3 to 0.2. The 500 iterations were given and solution was converged at 256 iterations.

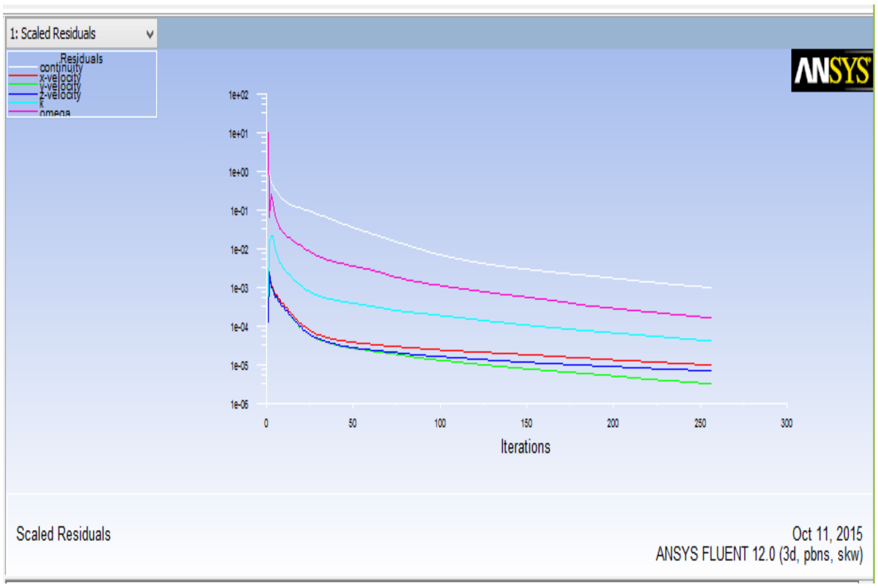


Fig. 7. Shows Convergence of Solution using k-ω model

We have also defined the MRF and value was given 20mrf. The initial velocity was given as 6 m/s to model. The velocity increased from 6 m/s to 13.54 m/s by means of 5 degree diffuser shroud with turbine inside.

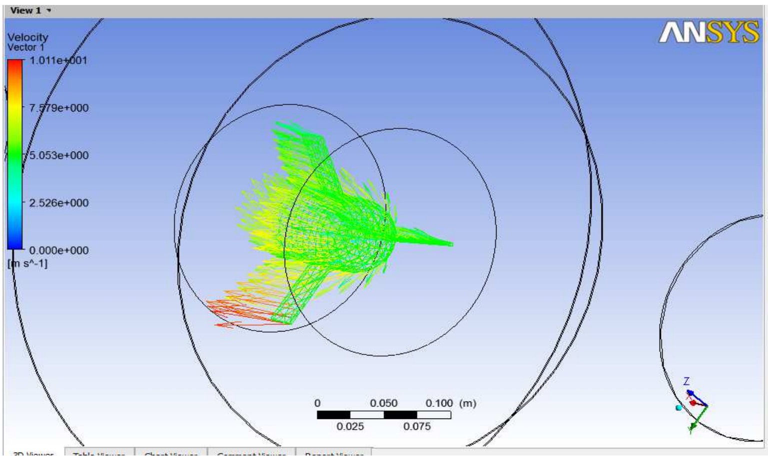


Fig. 8. Shows velocity vector on turbine

The Fig. 8 shows clearly that velocity has increased from 6 m/s to maximum 13.54 m/s around wind turbine. With increase in mass flow rate and increase in velocity the power output will also increase. In next attempt we changed some parameters such as we used k-epsilon model instead of k-omega model and 3rd order equations were applied. The initial value of velocity was given as 6 m/s. The value of MRF was 20 mrf and diffuser angle was 5°. The augmentation in wind was from 6 to maximum 9.96 m/s and solution was converged at 801 iterations. In this case we created the plane near diffuser inlet and we observed the augmentation in the wind velocity.

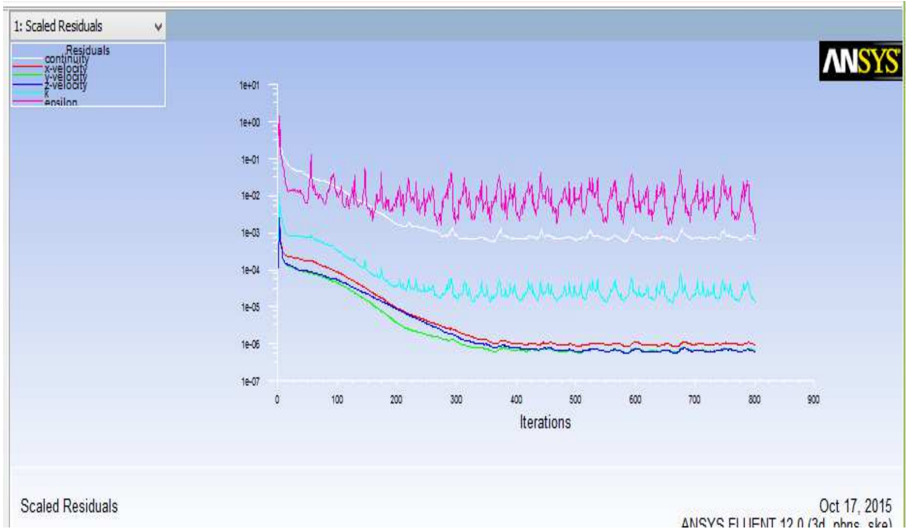


Fig. 9. Show the convergence using k-ε model

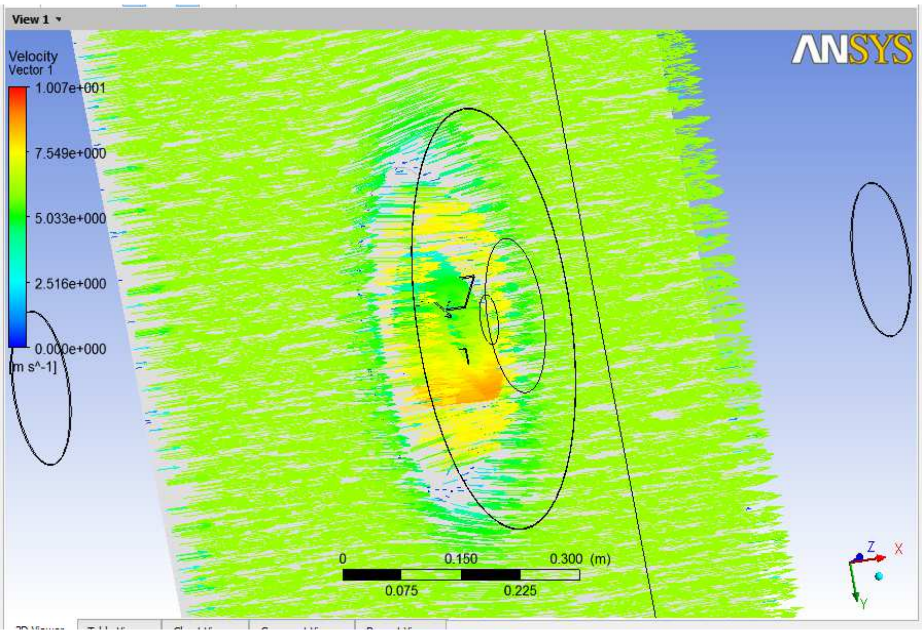


Fig. 10. Shows the velocity contour on plane created near diffuser inlet

Using function calculator we found that default area of interior was 0.00566 m^2 and volume was about near to 0.0039 m^3. The mesh report showed that number of nodes on MRF and static were 5780 and 162548 respectively. The number of elements on MRF and static were found tobe 28098 and 899927 respectively. The total number of node were 168328 and total number of elements were 928025. The force on turbine was 0.188N and area of turbine was 0.0226 m^2. Mass flow rate at Vin position was 23kg/s and volume at Vin position was 0.0059 m^3. The maximum value of velocity on turbine was 13.54 m/s and maximum value of velocity near diffuser inlet was 11.54 m/s.

For comparison between two methods k-ω and k-ε we run the solution again and we find that k-ε with 2nd order equations and with Vin 6m/s was converged at just 150 iterations. The maximum value of velocity on turbine was found to be 9.95 which shows there was augmentation of almost 4 m/s in wind velocity. However at the inlet of diffuser the maximum velocity was found to 9.0003 m/s. While k-ω with simplec 2nd order equations and with Vin 6 m/s was converged at 256 iterations. The maximum value of velocity was 13.56 m/s which shows that there was augmentation of almost 7.56 m/s in wind velocity and inlet velocity near diffuser was 11.54 m/s. Hence it was concluded that k-ω model was giving us more promising results than k-ε model.

Power curves between Diffuser augmented wind turbine and bare wind turbine clearly shows the power output of diffuser augmented wind turbine is higher than bare wind turbine.

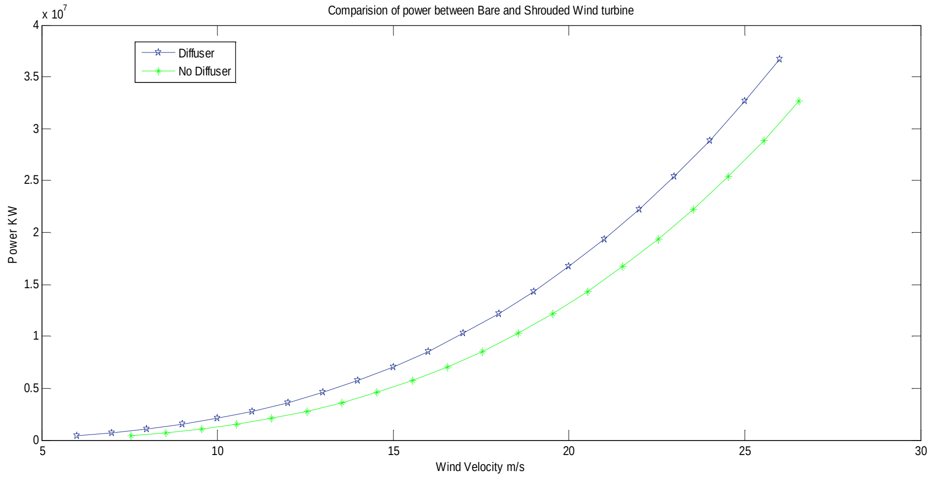


Fig.11. Shows the power comparison between Bare and Diffuser augmented wind turbine

The values of power obtained using diffuser augmented wind turbine and bare wind turbine are given below in the following table as a power10^6.

Table 1.Comparison between the diffuser and bare wind turbine

No Diffuser	0.45	0.71	1.52	1.7	2.09	2.78	3.61	4.59	5.73
Diffuser	0.89	1.3	2.4	2.89	3.21	4.12	5.18	6.2	7.8

The above given table shows that power obtained through diffuser augmented wind turbine is much higher than bare wind turbine. Hence, we can say that diffuser augmented wind turbine with flange can produce more power than the base wind turbine and also diffuser augmented wind turbine is best to install where wind speed is low. The power curve given above shows that power can be increased with diffuser augmented wind turbine almost 1.6-1.7 times according to our study, which is close to the values of Yuji Ohya results of experimental work. Hence this study confirms results of experimental work performed by Yuji Ohya a Professor in a Kyushu University Japan.

4. Conclusions

We simulated the wind accelerating device (diffuser with no turbine inside) that makes it possible to concentrate the wind energy. It was confirmed that hollow structure such as flange type diffuser is an effective for accelerating the wind. Based on iterations performed on ANSYS Fluent 12.0 at various conditions following conclusions are obtained:

- A properly designed diffuser with optimized dimension can be used to increase mass flow of wind.
- A diffuser having diameter of 0.4m, diffuser angle 5^0, and flange height of 0.2m is most effective design at reduced flow separation and improving wind speed from 6m/s to 13.5m/s.
- If we reduce the diameter further upto 3m or 2m that causes the turbulence and flow separation inside the diffuser.
- Flange type diffuser was more effective than without flange.
- K-ω model was giving better results than K-ε, because model constants of k-ω are less than the k-ε.

5. Future Work

Further research could lead to integrated diffuser and rotor design. A way to do this could be equating the thrust of diffuser to the rotor of blades. So if first the velocity distribution for an existing design is calculated and based on that an improved rotor design can be made. These calculations should be iterated till the convergence is obtained.

- Re-optimize the diffuser design and location of wind turbine inside the diffuser.
- Re-optimize the diameter, flange angle and flange height of diffuser to make the effective use of low density wind.
- To validate the present model an experimental setup of model dimension can be built and analyzed for different flow conditions.

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