Performance Evaluation of Small Wind Turbine Diffusers with Different Diameters

Sandip A. Kale, Rushikesh V. Godse, Haribhau G. Phakatkar

Abstract: Use of diffusers for increasing wind velocity is not a new concept. It is proven system through computational and experimental analysis carried out few researchers. Still, it is not well accepted technology and very few researchers are engaged in this research. Between computational and experimental analysis, researchers always prefer the computational flow analysis for evaluation of wind flow. The effect of diffuser diameter is an important aspect and this research paper is formulated on the same basis. In this research work straight conical converging -diverging vertical flanged diffusers are analyzed to study the performance. Ten different diffusers from 0.6 m to 6.0 m diameter are considered with the incremental step of 0.6 m. For all diffusers same geometry is used and simulated at the wind velocity 6.5 m/s. All dimensions of these diffuser models are considered with the same proportional by taking the rotor diameter as a reference. The velocity counters are studied and plotted. The velocity values measured in throat plane are plotted for all diffusers. Also, the multiple increase in velocity, power and coefficient of performance is plotted and discussed.

Index Terms: CFD, diffuser augmented wind turbine, wind turbine.

I. INTRODUCTION

Wind turbine power output is mainly depending on the rotor diameter and wind velocity. Power produced by a wind turbine is proportional to the square of rotor diameter and cube of wind velocity. Hence, to obtain, the more power from wind turbine one need to increase either the rotor diameter or wind velocity [1]. Large wind turbine manufacturers are always interested in increasing the rotor diameter to get more power output and achieved satisfactory performance also. These wind turbines are installed and operating in the windy regions after micro-sitting and site selection. The wind speed available at these sites is capable of producing expected electricity satisfactorily and economically. Small wind turbines are situated in the sites where, wind speed is less than that of the large wind turbines. As the power produced is proportional to the cube of wind velocity, low wind velocity significantly reduces the power output of small wind turbines. The output of the small wind turbine can be effectively increased by increasing the wind velocity.

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Covering the small wind turbines with diffusers is an efficient and economical method to increase the power output [2] [3]. Using diffusers for acceleration of wind speed to increase the power output is an old concept [4] [5]. Though this concept found very useful, the Diffuser Augmented Wind Turbines (DAWT) are still to be accepted by people because of some issues arise with the addition of the diffuser to the bare wind turbine [6] [7]. DAWT are more bulky, heavy and costlier than the bare wind turbine and also come across yawing performance. Because of advances in material sciences the intensities of these issues can be lowered considerably [8]. Researchers are always trying to reduce overall length and diameter of the diffuser without compromising the diffuser performance. Many researchers have carried out Computational Fluid Dynamics (CFD) analysis of diffusers of different geometries [9] [10].

This research work presents the wind flow study of straight conical convergent-divergent diffuser with vertical flange without rotor for diffusers with similar geometries but of different diameters.

II. METHODOLOGY

Table 1 shows the dimensions proportional of various geometrical parameters used for all diffuser diameters. Ten different rotor diameters are evaluated through the Computational Fluid Dynamic (CFD) analysis in this research paper. For all diffusers, input velocity is taken as 6.5 m/s. The minimum rotor diameter is considered for this study is 0.6m and maximum diameter as 6m. The rotor diameters increase in the step of 0.6m. The ten diffusers are denoted as $Diff_D$, where subscript D indicates diameter of diffuser in meters. For example $Diff_{0.6}$ indicates diffuser model for 0.6 m rotor diameter.

Table I: Details of fixed dimensional parameters

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Wind turbine rotor diameter (D)	=	D
Diffuser diameter at Inlet (D_1)	=	1.05D
Diffuser diameter at Throat (D_2)	=	1.03D
Diffuser diameter at Exit (D_3)	=	1.21D
Flange Height (H)	=	0.08D
Diffuser Flange diameter ($D_4=D_3+2H$)	=	1.37D
Entry to Throat Length (L_1)	=	0.07D
Throat to Exit Length (L_2)	=	0.25D
Total Length of Diffuser (L)	=	0.32D
Rotor tip to throat Gap (G)	=	0.015D

III. COMPUTATIONAL FLOW ANALYSIS

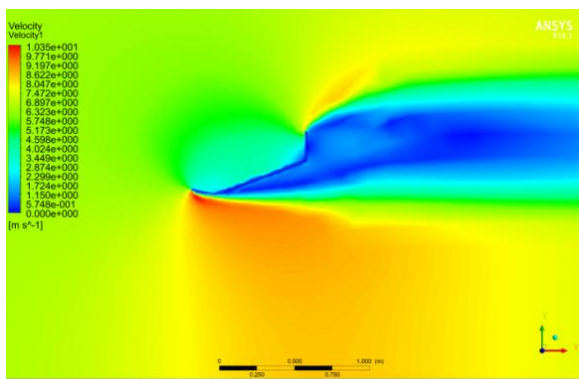Fig. 1 (a) to Fig. 1 (j) shows the velocity counters for all ten diffusers for the inlet velocity 6.5 m/s.
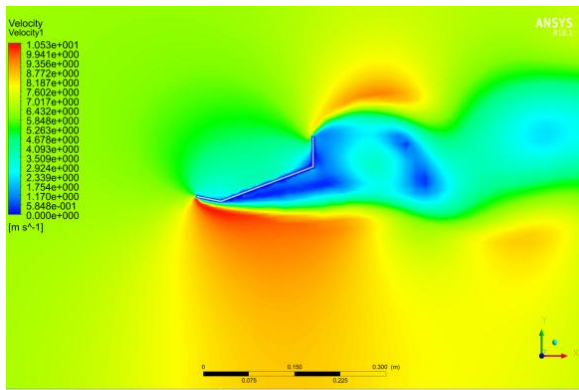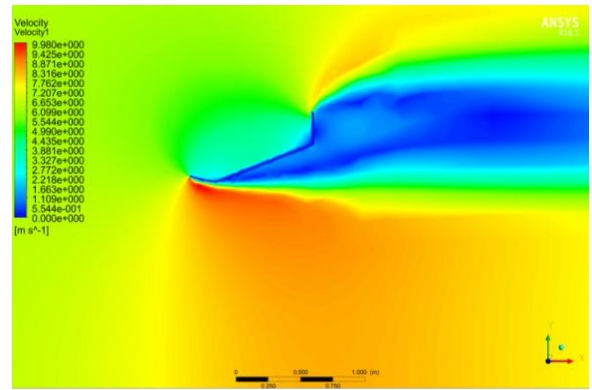

a. Velocity Counters for $Diff_{0.6}$
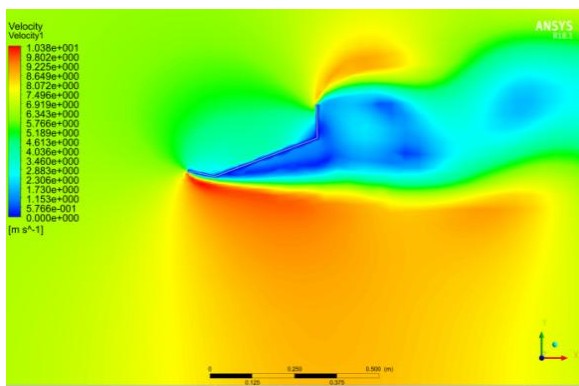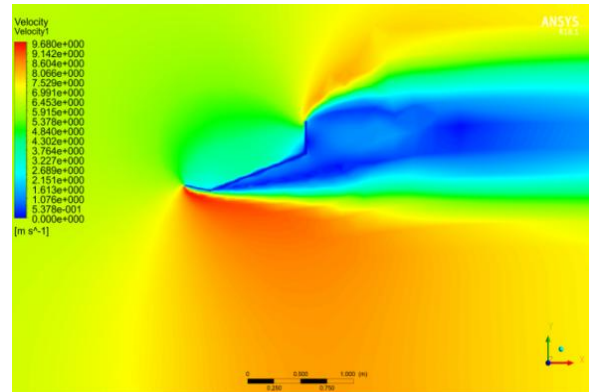

b. Velocity Counters for $Diff_{1.2}$
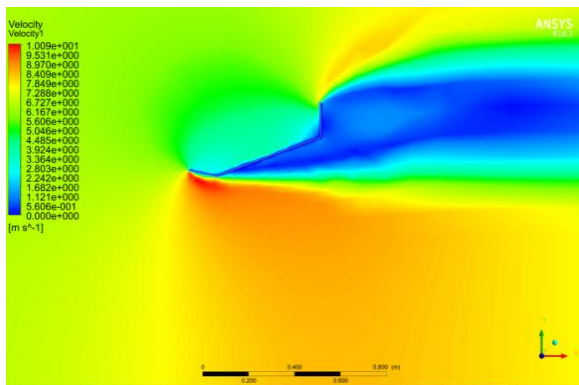
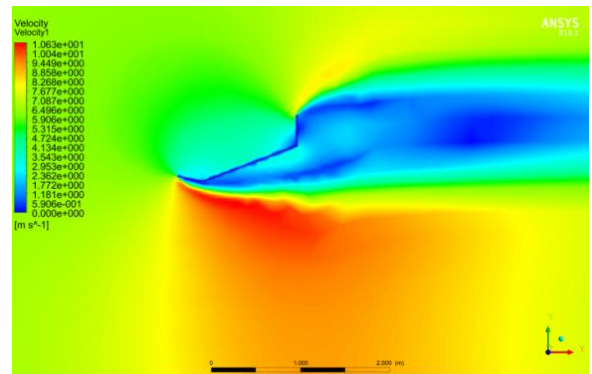c. Velocity Counters for $Diff_{1.8}$
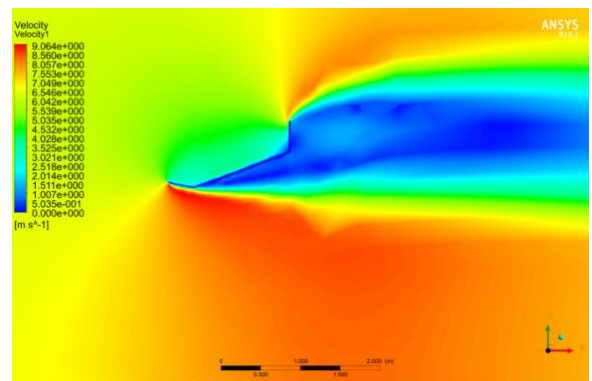

d. Velocity Counters for $Diff_{2.4}$
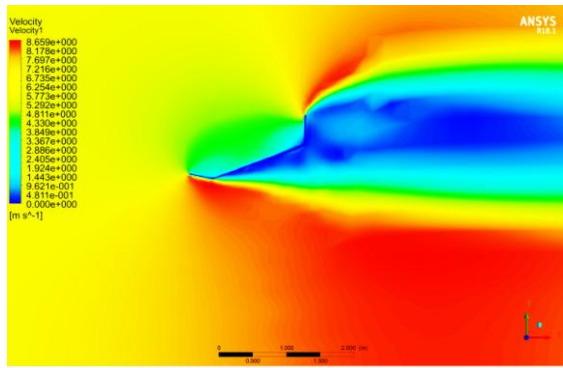

e. Velocity Counters for $Diff_{3.0}$
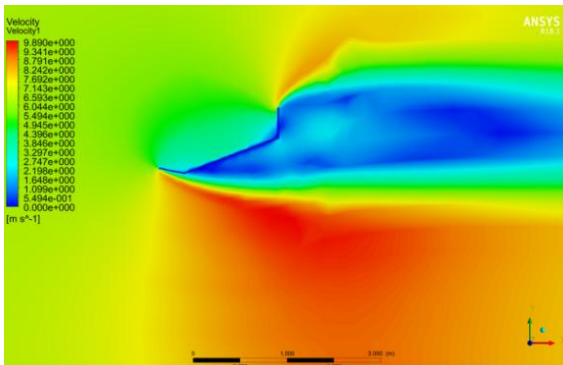

f. Velocity Counters for $Diff_{3.6}$

g. Velocity Counters for $Diff_{4.2}$

h. Velocity Counters for $Diff_{4.8}$

i. Velocity Counters for $Diff_{5.4}$

j. Velocity Counters for $Diff_{6.0}$

Fig. 1. Velocity Counters for all diffusers
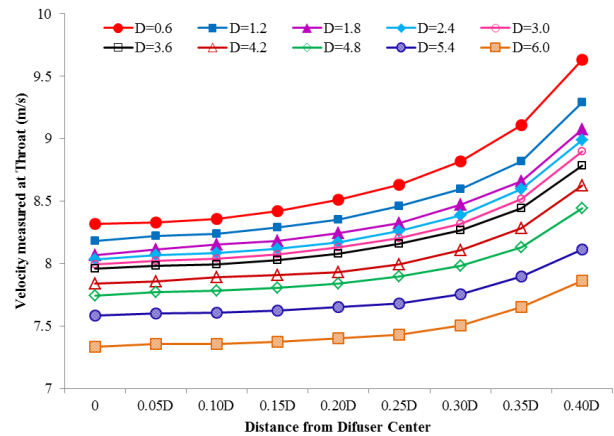
1.11 for $Diff_{6.0}$.

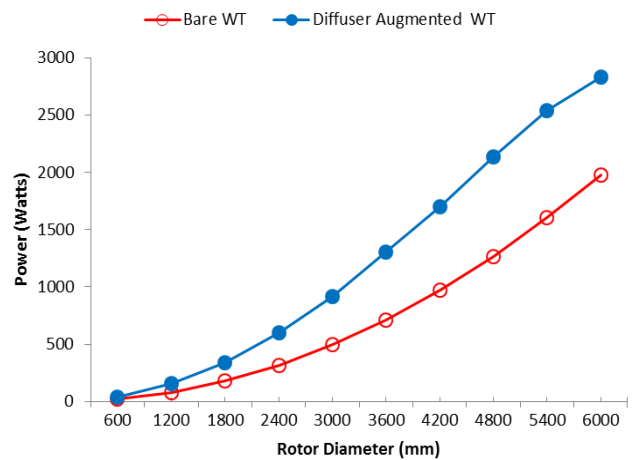**Fig. 2. Velocity distribution at throat for all diffusers**

Fig. 3. Theoretical power output for bare wind turbine and DAWT at wind velocity 6.5 m/s for all diffusers
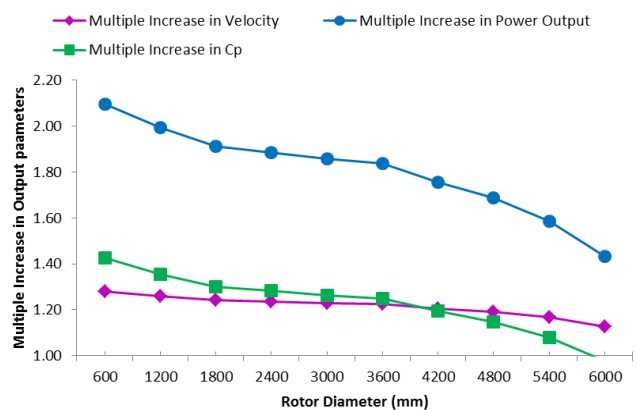

Fig. 4. Multipliers increase in velocity, power and C_p for DAWT at wind velocity 6.5 m/s with respect to bare wind turbine for all diffusers

IV. RESULTS AND DISCUSSION

Fig. 2 is plotted based on the velocity distribution occurred on the diffuser plane up to 0.4 D for all diffusers for the inlet velocity 6.5 m/s. From the plot it is clearly observed that the values of velocity are reduced with increased in the diffuser diameter. For smallest considered diameter ($Diff_{0.6}$) the wind velocity is 8.32 m/s at the central axis of the diffuser. It increases up to 9.32 m/s measured at distance 0.4 m from the central axis. For biggest considered diameter ($Diff_{6.0}$) the wind velocity is 7.33 m/s at the central axis of the diffuser. It increases up to 7.86 m/s measured at distance 0.4 m from the central axis. The difference in inlet velocity and increase velocity is found at 2.18 for $Diff_{0.6}$ and 1.16 for $Diff_{6.0}$.

Fig. 3 presents the theoretical power output for the bare wind turbine and DAWT at wind velocity 6.5 m/s for all diffusers. Since all DAWT power values are on the higher side compared to bare wind turbine power output. With the increase in diffuser diameters the velocity values are reduced for the same input values. In spite of this, it is observed that with increase in diffuser diameter, for the considered range it produces significant ore power than the bare wind turbine.

Fig. 4 is the plot of multipliers increase in velocity, power and C_p for DAWT at wind velocity 6.5 m/s with respect to bare wind turbine for all diffusers. With an increase in rotor diameter, multipliers of velocity, power output and coefficient of performance are decreasing. The multiple increase in velocity is found as 1.34 for $Diff_{0.6}$ and 1.18 for $Diff_{6.0}$. The multiple increase in power output is found as 2.38 for $Diff_{0.6}$ and 1.64 for $Diff_{6.0}$. The multiple increase in coefficient of performance (C_p)is found as 1.62 for $Diff_{0.6}$ and

Though, it is observed that the values of multipliers re decreasing, it cannot be declared that the diffusers are efficient for smaller diameter range. The evaluation presented in this research paper is a basic evaluation, but important for further research. This evaluation is based only on increasing the

diffuser diameters.

Still, there are many factors which can be jointly considered for comprehensive evaluation for wind turbines of various rotor diameters.

V. CONCLUSION

From the computational analysis carried for diffusers of similar geometry with different diameters following conclusions are listed,

- With an increase in diffuser diameter the values of velocity obtained are reduced.
- The multiple increase in velocity is found as 1.34 for $Diff_{0.6}$ and 1.18 for $Diff_{6.0}$.
- The multiple increase in power output is found as 2.38 for $Diff_{0.6}$ and 1.64 for $Diff_{6.0}$.
- The multiple increase in coefficient of performance $(C_p)$is found as 1.62 for $Diff_{0.6}$ and 1.11 for $Diff_{6.0}$.

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