POWER GENERATION BY DIFFUSER AUGMENTED WIND TURBINE

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ABSTRACT
Brimmed diffuser is collection–acceleration device which shrouds a wind turbine.For a given turbine diameter, the power augmentation can be achieved by brimmed diffuser, popularly known as wind lens. The present numerical investigation deals with the effect of low pressure region created by wind lens and hence to analyze the strong vortices formed by a brim attached to the shroud diffuser at exit. Also in this analysis, a comparative numerical prediction of mass flow rates through the wind turbine has been carried out with various types of wind lens which in turn helps to optimize the torque augmentation. It has been numerically proved that there is significant increase in the wake formation & vortex strength when brimming effect is added to a diffuser

KEYWORDS: Windlens, Windturbine, DAWT, Brim

INTRODUCTION

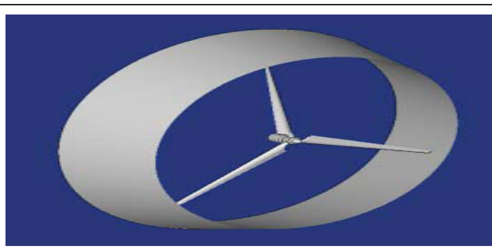
An increase in the efficiency of a wind power generation is important from the point of view of preventing global warming of the earth by sustainable energy. Among others, wind energy technologies have developed rapidly and are about to play a big role in a new energy field. However, in comparison with the overall demand for energy,the scale of wind power usage is still small; especially, the level of development in Japan is extremely small. As for the reasons, various causes are conceivable. For example, the limited local area suitable for wind power plants, the complex terrain compared to that in European or North American countries and the turbulent nature of the local wind are pointed out. Therefore, the introduction of a new wind power system that produces higher power output even in areas where lower wind speeds and complex wind patterns are expected is strongly desired.

A wind lens is a modification made to a wind turbine to make it a more efficient way to capture wind energy. The modification is a ring structure called a "brim" or "wind lens" which surrounds the blades, diverting air away from the exhaust outflow behind the blades.Windlens turbine is also well known as Diffuser Augmented Wind Turbine (DAWT) .Wind power generation is proportional to the wind speed cubed. Therefore, a large increase in output is brought about if it is possible to create even a slight increase in the velocity of the approaching wind to a wind turbine. If we can increase the wind speed by utilizing the fluid dynamic nature around a structure or topography, namely if we can concentrate the wind energy locally, the power output of a wind turbine can be increased substantially. Although there have been several studies of collecting wind energy for wind turbines reported so far, it has not been an attractive research subject conventionally.

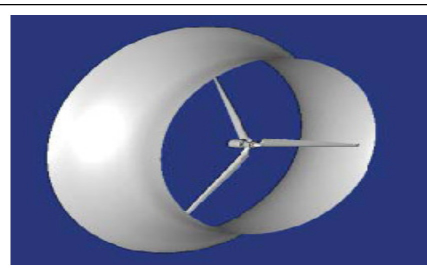
COMPUTATIONAL METHODOLOGY

PHYSICAL MODEL:

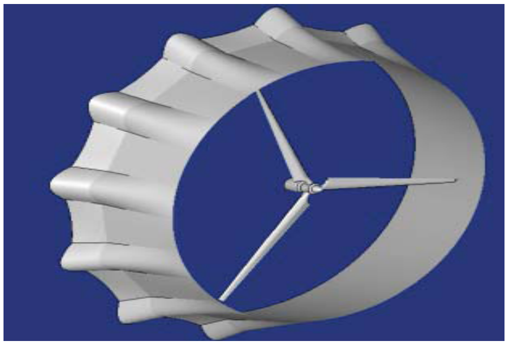
A conventional wind turbine model is considered for the present numerical investigation. The rotor diameter of the turbine is 3.5 m and clearance between rotor and diffuser section is set to have 0.1m. Inclusive of conventional straight diffuser there are four different types of diffusers of curved, stepped and bumped configuration have been designed with the length of 0.28 times of the diffuser diameter and assembled to align with the wind turbine. The inlet and exit diameters of the diffusing passage is kept constant and the outer surface of the diffuser is modified to get different flow pattern and vortex formation. Figure shows the various diffuser configuration used for present analysis. To strengthen the wake formation at the outer of diffuser a flange type brim is attached with all four configurations for further numerical investigations.



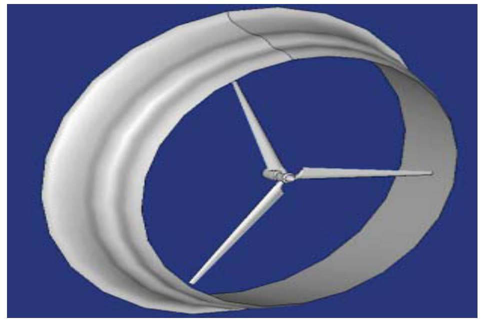
1. Straight Diffuser



2. Curved diffuser



3. bumped diffuser



4. Straigth Diffuser

Fig. 1Various diffuser configuration used for present CFD analysis

MESHED DOMAIN:

The computational domain of dimension 17m*10.5m*10.5m considered for the present analysis is shown in figure 2. An unstructured tetra mesh is formed in the flow domain for computations.A growth rate of 1.4 is maintained from the geometric surface to the domain surface.The total cell count considered for the computational analysis is 2.8 millions.The fluid volume mesh is refined near the WT rotor & the $y^+$is maintained within 50 to capture the wall shear effects.

Fig. 2 Meshed domain model of bumped diffuser

Fig.3 Meshed Model of WT rotor & Diffusing Passage

NUMERICAL ANALYSIS

The computational analysis or the discretized fluid domain is carried out with a commercial numerical fluid dynamics codes which solves pressure based NAVIER STOKES (PBNS) equations. A 3D steady, incompressible and isothermal flow is simulated in the flow field by invoking a standard k-epsilon turbulence model for predicting the viscous effects over the surfaces. Inlet of the fluid domain is given with 'velocity-inlet' boundary condition of magnitude 14m/s and the outlet is given with 'pressure-outlet' boundary condition of gauge pressure of 0 Pascal with a reference pressure of 1 atm. Standard wall functions with no-slip boundary condition are applied on the surfaces of wind turbine, hub, diffuser, generator, brim etc. The solution method follows a SIMPLE algorithm with pressure-velocity coupling and second order upwind scheme is used for solving momentum and turbulence equations. Mesh independence study has been carried out to the straight diffuser configuration where the mesh count is varied with very course mesh to refine mesh level for which the average mass flow rate is calculated .It is observed from the pilot(figure 3) the flow rate is independent of mesh count after 2.8 million elements. With this reference, all other configuration are meshed & maintained with the same refinement

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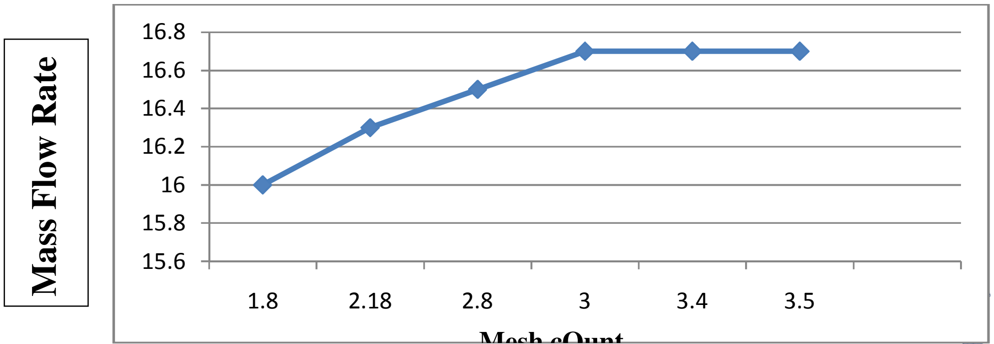


Figure 3. Mesh Independence study for straight diffuser configuration

RESULTS AND DISCUSSIONS

Effects of Brimmed Diffuser Wind lens: Numerical simulation of flow field around the wind turbine is carried out & the simulated result significantly predict the effect of diffusing passage & its brimming effect around the blades.The turbulence intensity around the wind diffusing is shown in figure 4. Also figure 5 shows the comparison of a bare wind turbine with diffusing & brimming effects.The velocity contour shows a significant increase in wake formation behind the brimmed diffuser which causes a reasonable low pressure region behind the turbine .This low pressure region draws more air flow rate to strike the turbine which in turn augments the torque.

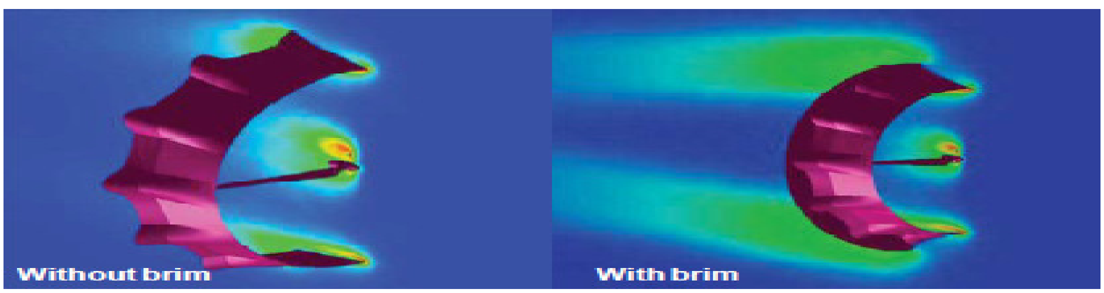
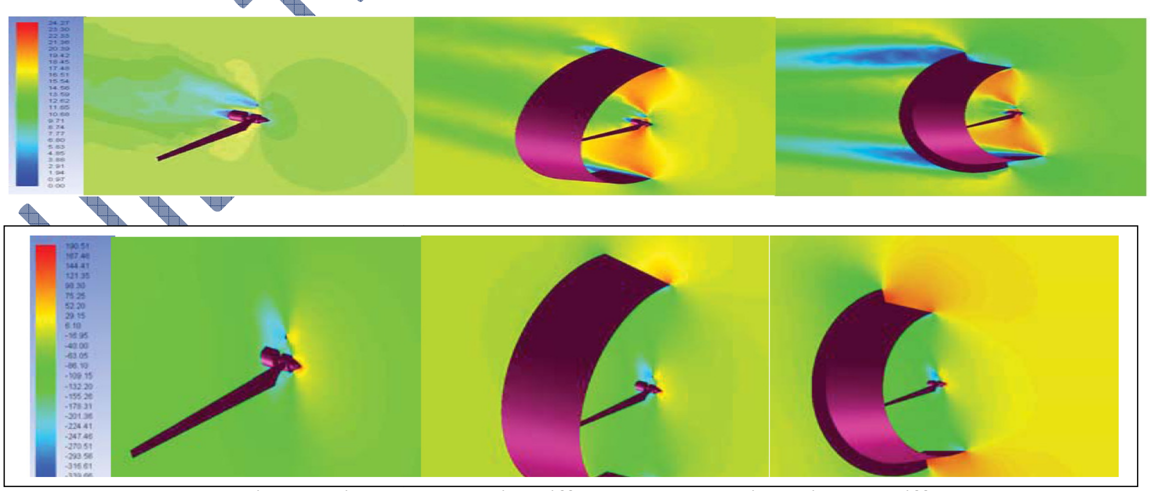


Figure 4. Turbulence Intensity with and without brim



Bare wind turbine **with diffuser** **with brimmed diffuser**

(a)Velocity variation b)Static Pressure variation

Fig 5. Effect of Diffusing Passage & Brimmed around the wind turbine

Various diffusers with straight, curved, stepped and bumped configurations have been numerically investigated for optimum mass flow rate conditions through wind turbine. The variations of statics pressure over that the diffuser configurations with and without brim are shown in figure.5 It is observed that the bumped and curved diffusers with brim have more static pressure rise while comparing with other two diffusing passages. It can be seen that power coefficient with shroud is greater than that without shroud and shows a definite available air power increase due to velocity increase of air due to sucking effect of shroud. However tip speed ratio is less than one and the power generated is very low which is due to excessive drag force.

Figure 6Shows the percentage increase in mass flow rate for all four brimmed diffuser configuration while comparing with the bare wind turbine.

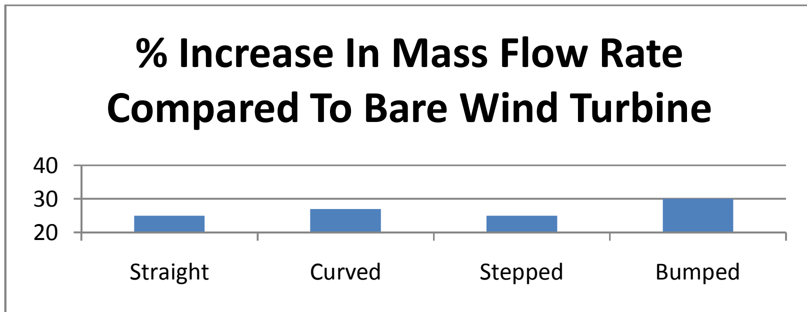
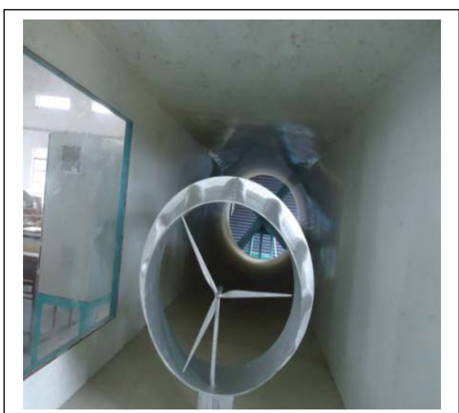
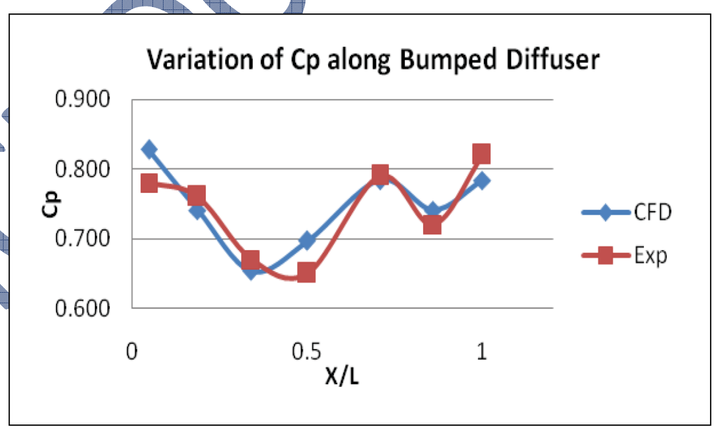


Figure 6 .percentage increase in mass flow rate

Experimental Validation: The above numerical results have been validated by considering the pressure distribution over the diffusing passage.A conventional for the experimental validation as shown in figure 7 (a) and 8 (a) .Pressure variation is found a long the outer surface of the diffuser & compared with the CFD result as shown in Figure 7 (b) and 8(b).The experimental values of c_p. are found to be in line with CFD values.





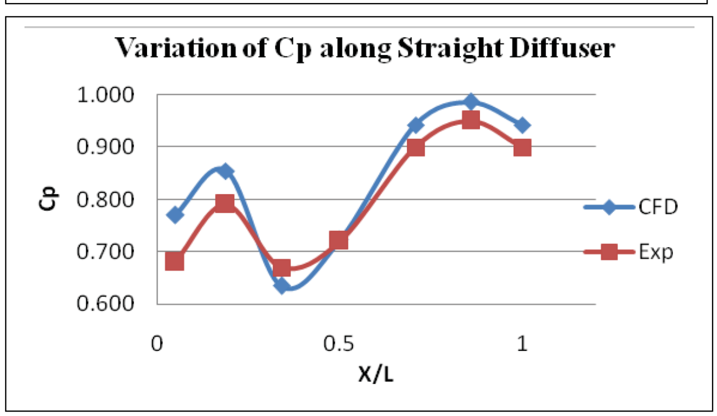


Fig .7 Experimental (a) set up& (b) validation of bumped diffuser
Fig. 8 Experimental (a) set up (b) validation of straight diffuser

CONCLUSION

The above series of studies show the effect of diffusing passage around the wind turbine.It is observed that presence of diffuser induces wake form action which in turn reduces the pressure behind the wind turbine.The strength of low pressure region & wake formation can be augmented by adding a brim at rear end of diffuser.On numerical investigation of various configurations of diffusers,it is observed that the low pressure region is more pronounced in bumped configuration with brim.This gives a significant increase in mass flow rate available for wind turbine.

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