Design & Analysis of Diffuser for Wind Mill

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Abstract— Flanged Diffuser is collecting-accelerating device which shrouds a wind turbine. For 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 & hence to analyze the strong vortices formed by brim attached to shrouded diffuser at the exit. Also in this analysis, a comparative numerical prediction of mass flow rates 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 proved that there is significant increase in the vortex strength & wake formation when brimming effect is added to a diffuser.

Key words: DAWT, Windlens, Brim, Vortex, Wind Turbine, CFD

I. Introduction

For application of an effective energy resource in future, the limitation of fossil fuels is clear and the security of alternative energy sources is very important subject. Furthermore, due to environmental issues, i.e., global warming, etc., application of renewable and clean energy are strongly expected. Amongst all others, wind energy technology have developed rapidly and are about to play a important role in a new energy field. Compared to the global demand for energy, the scale of the use of wind energy is very small. As for the some reasons, various causes are occurred. For example, the limited local area for wind power plants, the complex terrains compared to that in European or North American countries & the turbulent nature of the local wind noted. Therefore, the idea of new wind power technology provides the highest power output in complex wind patterns and where wind speed is much lower.

Power generation by using wind is directly proportional to the wind cube speed . That's why, for increasing the output we should have to increase the velocity of the approaching wind to a wind turbine. If we utilizing the fluid dynamic nature around a structure or topography we increase the wind speed namely if we concentrate the wind energy locally also the power output of a wind turbine be increased. This study is regarding the improvement of a wind power system with more output, aims at determining how to collect the wind energy effectively and which kind of wind turbine can generate energy efficiently from the wind. There are some hopes for utilizing the wind power by more efficient way. In this present study, the concept of accelerating the wind was named the "wind lens" technology. The wind turbine with a brimmed or flanged diffuser shroud -so called "wind lens turbine"- is developed as one of high performance wind turbines. The wind-lens turbine generate electric power even in low speed wind since the brimmed-diffuser shroud increases the velocity of wind at rotor .Wind lens windmill is a compact shaped high-efficient urban small windmill that can be installed anywhere. It has been greatly increases the output by mounting the special ducts on blades than conventional wind power generator. To overcome various problems in the conventional wind power generation by reducing the noise, can now small wind power generator which can be easily installed to date areas. A special duct is attaching around the rotor, and it generates a strong vortex in the rear of the wind turbine. Because of the vortex, lowers pressure region is produced at the back of the windmill, it accelerated the speed of the wind that flows into the duct (see figure 1) .As power generated by wind turbine is proportional to the cube of the wind speed, it is possible to increase output approximately 3-fold when compared to the absence of the duct. Furthermore, the rotation area of the blade (sound source) is that and the current Fluidic structure itself is compact and has achieved excellent silence because it suppresses the blade tip vortex that becomes the noise source. In addition, since the collector-style lens is surrounded by a blade, it also obtained a visual sense of security.

Below figure 1 shows the principle of wind lens & figure 2 shows the Don Qi Urban Windmills is one of these 'green' initiatives stimulated by the Dutch government subject conventionally.

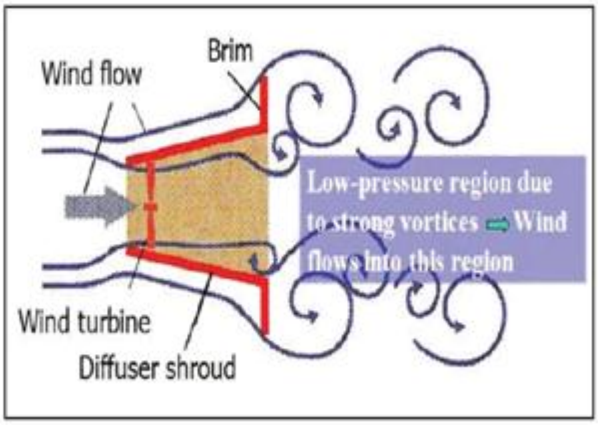

Fig. 1: Principle of increase in the mass flow rate of the air

Unique research that was carried out in the past is the examination of a DAWT by Gilbert. Gilbert and Foreman, Igra and others around 1980. In their studies, there was a focusing on concentrating wind energy in a diffuser with a huge open angle, a boundary layer controlled with few flow slots was employed. Therefore pressure loss of the prevented by flow separation with boundary layer control and increases in the mass flow inside diffuser. On the basis of this idea, a group in New Zealand developed an increased wind turbine with Vortex diffuser. A wing-profiled ring structure developed with a shrouded wind turbine by Bet and Grassmann. The result was that its DAWT showed an increase in power by a factor of 2, compared to the conventional wind turbine. This present study is about the improvement of a wind power system with high output, aims at determining to collect the wind energy effectively and what kind of diffuser can generate energy efficiently from the wind.


Fig. 2: the DonQi Urban Windmill

II. PROBLEM DEFINITION

We are facing the problems that the windmills are unable to be constructed on the lower surface. As a wind mill need 40 Km/hr to rotate its blade. The speed was unable to be achieved on the lower surface. And the cost of wind mill to produce electricity was also high and the output was less as compared to investment. There are many natural accidents were taking place like the bird were unable to understand where to fly and they used to fly in between rotating blade and hit by blade. Due to this the whole system used to stop and need to be cleaned and restarted again. Manpower consumption was high for this process as it was a huge heighted wind mill.

III. OBJECTIVES

The moto of wind lens is to improvise wind turbine power generating capability by:

1) Check high efficiency diffuser amongst straight diffuser, stepped diffuser, curved diffuser, bumped diffuser.
2) Increasing wind kinematic energy via rotor and maintaining wind turbine system axial load.
3) Increasing wind turbine rotor speed.
4) Reducing variation in wind speed

IV. SCOPE OF THE WORK

Scientist have done experiments on wind lens by constructing prototype models and validated by numerical methods .The overall design is done by research into shroud and wind lens flow augmentation .An angular ring with an air foil cross section is utilized to channel flow towards the turbine rotor. Diffuser / brim portion behind angular channel is designed by the generals vertices behind turbine rotor, behind the wind region it create lower pressure

V. METHODOLOGY

A. To check high efficiency turbine amongst straight diffuser, stepped diffuser, curved Diffuser, bumped diffuser

In this thesis firstly we make the models in CREO which have dimensions are as follows: blade diameter = 0.61m, diffuser diameter =0.65m. Checking the efficiency of above mentioned four diffuser type by using ANSYS FLUENT Software amongst those which have high efficiency we make the model of that diffuser.

B. To increase the wind kinetic energy through the rotor while maintaining reasonable wind turbine system axial loads.

After checking the efficiency of above diffuser we will choose high efficient model and after that we goes for experimental analysis

C. To increase wind turbine rotor speed.

After checking above all parameters we will mount the diffuser of suitable diameter at suitable distance for high power output. By this way we increase the speed of rotor for low wind speed.

VI. LITERATURE REVIEW

Raju Govindharajan [1] checked the performance of different types of diffuser. From his study he 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 the rear end of diffuser. On numerical investigation of various configuration of diffuser ,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.

Yuji Ohya, Takashi Karasudani [2] who invent a collection-acceleration devise for wind, “the brimmed diffuser”, which shrouds a wind turbine. Significant increase in the output power of a microscale wind turbine was obtained. Increase in the output power of approx four to five times of conventional wind turbine is gained with a relatively long diffuser (Lt+1.47D).

Kazuhiko Toshimitsu,Taiga Arakane et al. [3] presents the paper on performances of the only rotor turbine and the compact-type wind-lens turbine in steady and unsteady winds. In steady wind, the flow structure around the wind-lens turbine is made clear by PIV. The compact wind-lens turbine generates larger power than the only rotor wind turbine. In unsteady wind, the performance of the wind turbines is investigated for the upstream mean velocities 5m/s with the sinusoidally oscillating with amplitude 1.0 m/s at frequencies 0.033,0.05,0.083 and 0.25Hz.

Abhishek Mohan Menon, Ananthapadmanabhan S.R. et al. [4] done very sincere attempt in the development and experimental demonstration of Wind Lens Energy Recovery System (WERS) . The available wind power ($P=\frac{1}{2} \rho AV^3$) ,P = power in watts,ρ = The air density ($1.2 kg/m^3$ @ sea level and 20° C),A = The swept area of the turbine blades (m^2),V = wind speed (m/s) increased from 13.58 W without shroud at a free stream velocity of 7 m/s to 20.27 W with shroud which shows a consistence increase in velocity.

Therefore, power by 66.99%.Curve between power coefficients, tip speed ratio is plotted for both with and without shroud respectively. The maximum power without shroud respectively .The maximum power without shroud is $9.42*10^{-5}$and with shroud is $6.81*10^{-3}$.

Yuji Ohya,Takashi Karasudani [5] done a field experiment for 500W Windlens .The result shows a significant increase of power output as much as 400% compared to conventional turbine. For larger turbine size of brim and reduction of mass is necessary.

A.K.Prema [6] present a paper on topic "Wind lens Technology for Power Generation" in his paper he told that " The most distinctive feature of Wind-Lens Turbine is a brimmed diffuser surrounding the turbine blades. The wind lens has a hollow frame cover with a wide ring edge at the output periphery. The strong vortices created by the diffuser and the brim produce an area of low pressure behind the turbine that essentially sucks the wind inside the diffuser. As a result, wind speed flowing into the blades is increased by 1.3 to 1.5 times. This is collection acceleration effect. Energy output is directly proportional to the cubed wind speed. That means if wind speed can be accelerated, energy output can increase as it cubed. At the same wind speed, wind-lens triples turbine output. Energy o/p is proportional to wind speed v cubed if wind speed entering the turbine is magnified by 1.4 times, triple energy o/p can be generated."

Sandip A. Kale,Yogesh R. Gunjal et al. [7] in their work computational fluid dynamics analysis is carried out for three different diffusers – diffuser without flange, diffuser with vertical flange and diffuser with inclined flange for a micro wind turbine. The purpose of work is optimization of diffuser to gain maximum wind velocity. The design of diffuser is for horizontal axis micro wind turbine of rotor diameter 1200 meter. The length of diffuser is taken as only 0.25 times rotor diameter and less than 0.2 times diffuser diameter. The curve sectional shape is designed as combinations of curves from cycloid category. The flange height is 10 percent of rotor diameter. In inclined flange diffuser, flange is inclined at 100. From his CFD analysis, it is observed that vortex is shifted to mean flow path of diffuser and hence negative pressure at the downstream of the diffuser which accelerate the flow results in increase in mean velocity in the diffuser & velocity increased to maximum of 13.4 m/s at the tip of turbine and nearly 10 m/s at the centre of diffuser with 100 inclination of flange with vertical.

Sandip A. Kale, Dr. S. N. Sapali [8] in their research paper they give review on multi rotor wind turbine & comes to conclusion that a new model developed for complete assessment of multi cost depends on number of small rotor. Advantages can be taken for array wind turbine .while comparing three wind turbine unidirectional co-axial series rotor wind turbines unidirectional co-axial series rotor wind turbine show case encouraging rays. Based on this invention, vortex diffuser argumented wind turbines were created by a people in New Zealand. Rather , the resulted DAWT show cased an height in power output by a factor of two.

VII. Diffuser Augmented System

A. Airfoil Blade

From Air foil blades I have selected the NACA air foil profile as is effective and ease of fabrication. The material used to blade is wood.

Fig. 3: NACA 63(2)215 Airfoil blade

B. Hub

The hub in which the blades are inserted is made of Aluminium. Using screw the spindle of the motor can be fired together. Blades requires: free stream velocity 6 m/s. Angle for attack 6 blades wood hub diameter 0.05 m. Hub material: Aluminium.

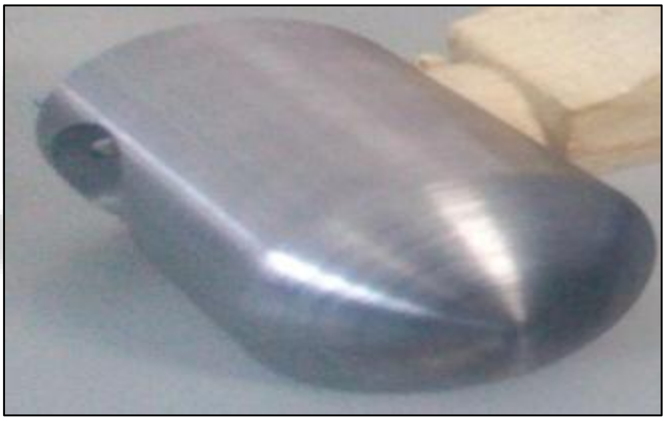

Fig. 4: Hub

C. Wind Lens (shroud)

Based on design, made by Yuji Ohya and Takashi Karasudani .we fabricated the same with a throat diameter of 1.3 m with all other dimensions relative to the throat diameter.

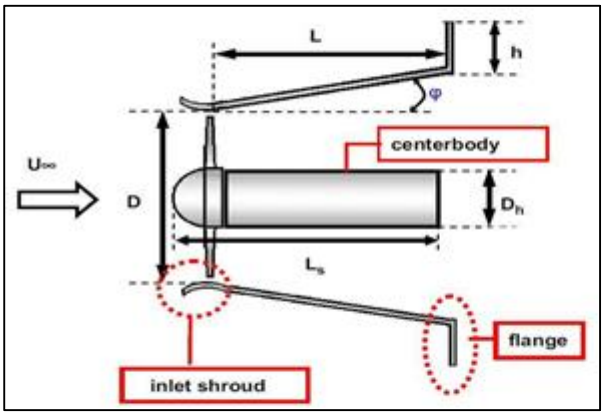

Fig. 5: Diagram of shroud with Dimension D=0.65 m
L = 0.18 D = 0.115 m

Ls = 0.45 L = 0.05 m
Dh = 0.08 D = 0.05 m

h = 0.1D = 0.065 m
Ø= 230
U∞ = 6 m/s (approx.)

1) Material used: G.I sheet

Fig. 6: Diffuser

D. Generator

Here a D.C to A.C generator was selected due to it has low starting torque as well as small size so that it obstructs little amount of air.

VIII. DAWT EQUATION

The following data shows the meaning of variables used in this model:

E = Kinetic Energy in J
ρ = Density in kg/$m^{3,}$
(m = Mass in kg)
A = Swept Area m^2
v = Wind Speed in m/s
Cp = Power Coefficient
P = Power in W
r = Radius in m

=Mass flow rate in kg/s

x = distance in m

= Energy Flow Rate in J/s

t = time in s

At constant acceleration, the kinetic energy of an object having velocity (v) and mass (m) is equal to the work done (W) .

E =W = Force × Displacement= F×s According to Newton’s Law, we have:

F = m×a

Hence,

E = m×a×s … …………….(1)

From the third equation of motion:
v2 = u2 + 2as
we get:
a= 2− 2

2
Since the initial speed of the object is zero, i.e.

u = 0,
We get:
a = 2

2
Substituting value of ‘a’ in equation (1), we get the kinetic energy
E = 12mv2 ………………..…… (2)

The power in the wind is equal to the rate of change of energy:
P = = 2 dm …………..….. (3)

2
As mass flow rate is given by:

= A

and the velocity is given by:

v =

we get:

= ρAv

Hence, from equation (3), the power can be defined as:
P = 12ρAv3 ……………….…..(4)

A German physicist Albert Betz concluded that any wind turbine can not convert more than 59.3% of the kinetic energy of the wind into rotary mechanical energy. Now a days, this is known as the Betz Limit or Betz'Law. Therefore maximum theoretical efficiency of the wind turbine is 0.59. This is called as the power coefficient and is defined as:

Cpmax =0.59

At this higher limit the wind turbines cannot operated. The Cp value is same to each turbine type and it is a function of wind

Velocity that the turbine is operating in. Whenever we deal with the various engineering requirement of the wind turbine durability and also strength in particular real world limit is below Betz Limit with values of 0.35-0.45. By taking all other parts into account in a whole wind turbine system for e.g. the generator, gearbox, bearings etc., only 10-30% of the power of the wind converted into usable electricity. The available wind power is given by:

P avail=12 ρAV3Cp……………. (5)

The turbine swept area is given by:

A = πr2 …………………….. (6)

Where the radius is acts as the blade length as shown in the figure below:

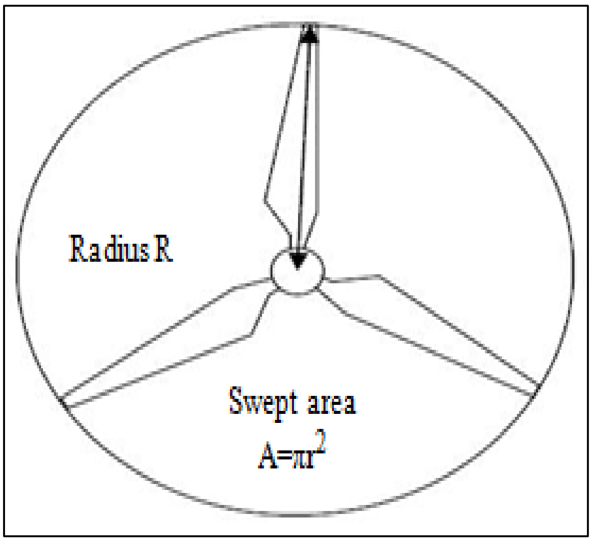

Fig. 7: Schematic diagram of wind turbine with diffuser

IX. CAD MODEL

The basic 3D model was drawn on CREO software. Following figures shows the cad model of various type of diffusers i.e. straight diffuser without brim, straight diffuser with brim ,curved diffuser without brim, curved diffuser with brim, stepped diffuser without brim & stepped diffuser with brim, bumped diffuser without brim, bumped diffuser without brim,. In this analysis, firstly we create the above mentioned 3D models with suitable dimensions. After that we use this model for CFD analysis in ANSYS FLUENT software.

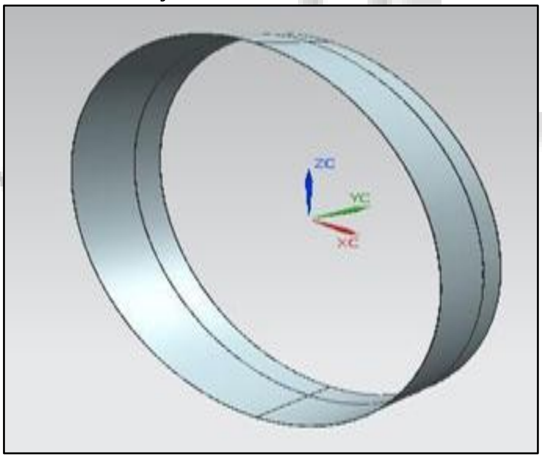
Fig. 8: Straight diffuser without brim

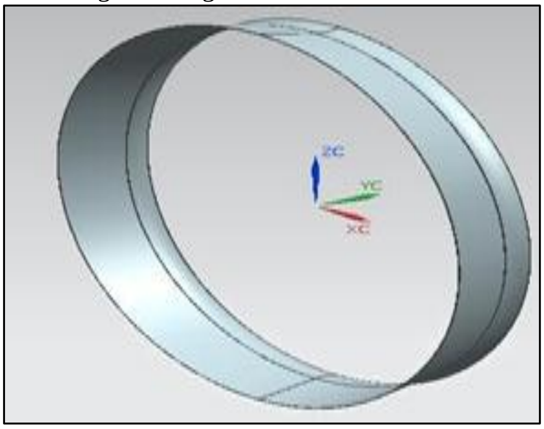
Fig. 9: Curved diffuser without brim

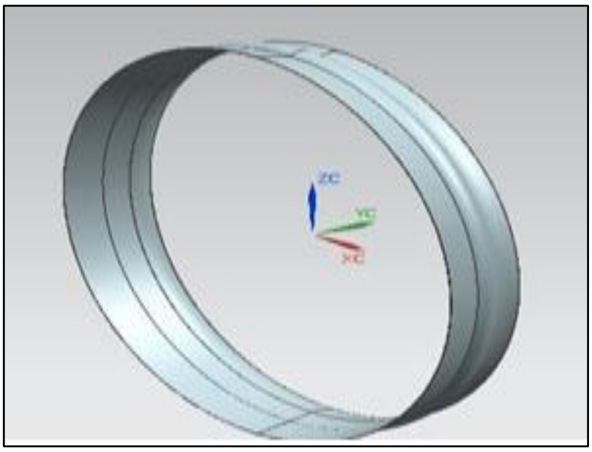
Fig. 10: stepped diffuser without brim

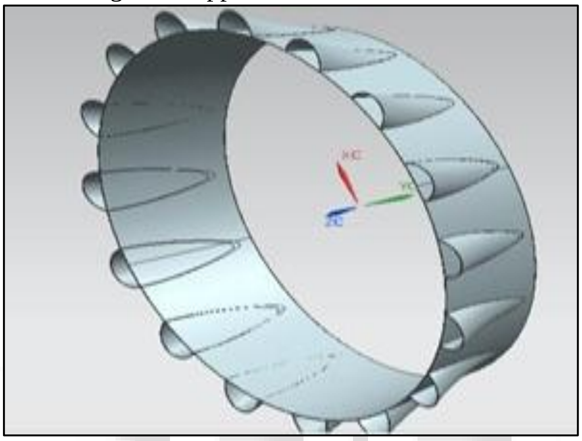
Fig.11: Bumped diffuser without brim

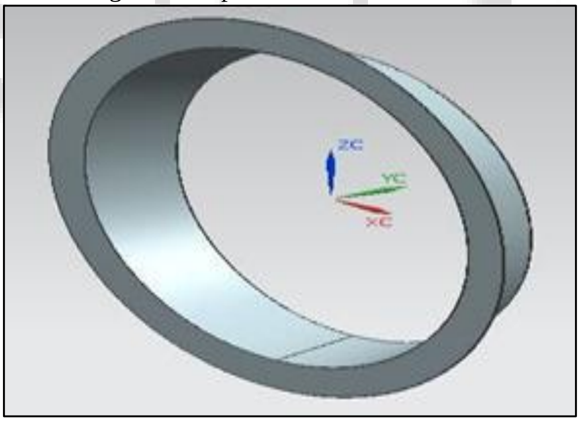
Fig. 12: Straight diffuser with brim

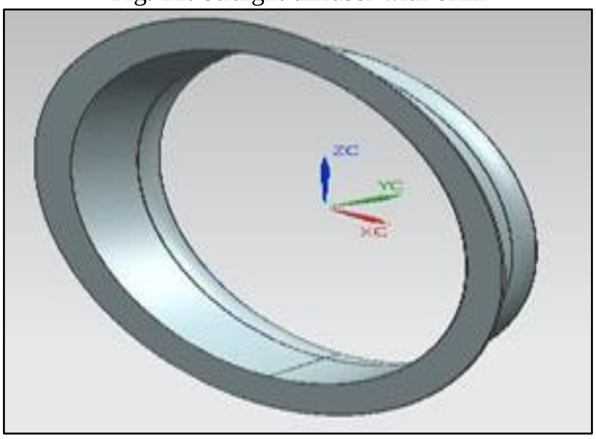
Fig. 13: Curved diffuser with brim

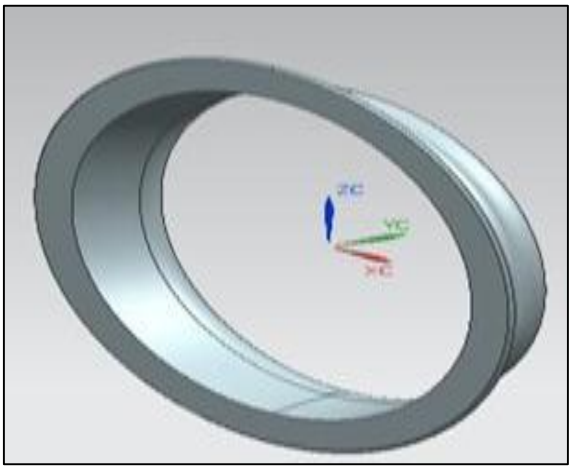

Fig. 14 stepped diffuser with brim

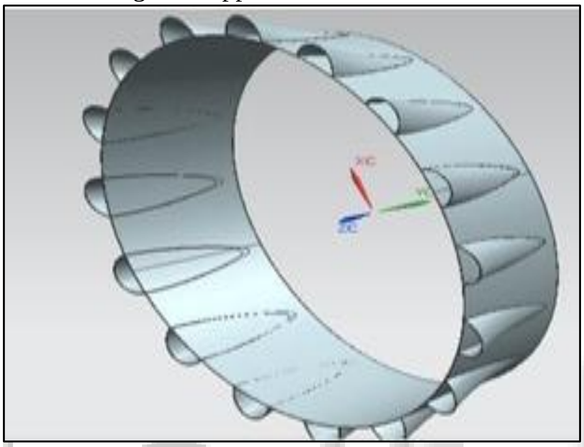

Fig.15: Bumped diffuser with brim

X. CFD ANALYSIS

Above created 3D models of various diffusers are used for CFD analysis in ANSYS FLUENT version 14.5. Following figure will shows the velocity contour & pressure contour of all diffusers. After doing CFD analysis we will find which diffuser will give high output velocity, because power generated by turbine is directly proportion to the cube of velocity. So that's why we will take pressure & velocity contour of all diffusers.

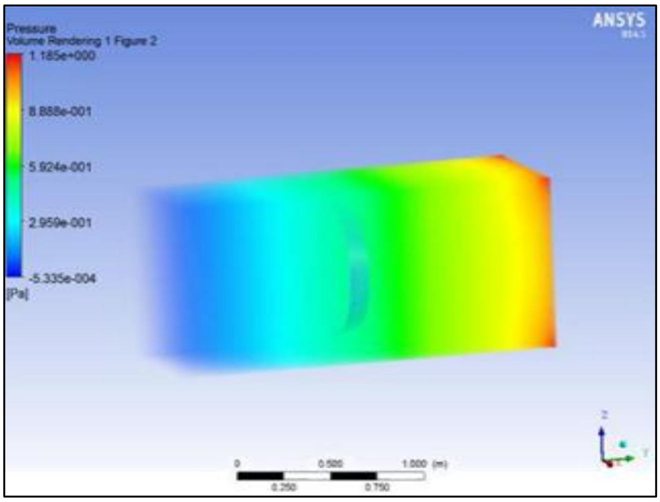

Fig. 16: pressure contour of straight diffuser without brim

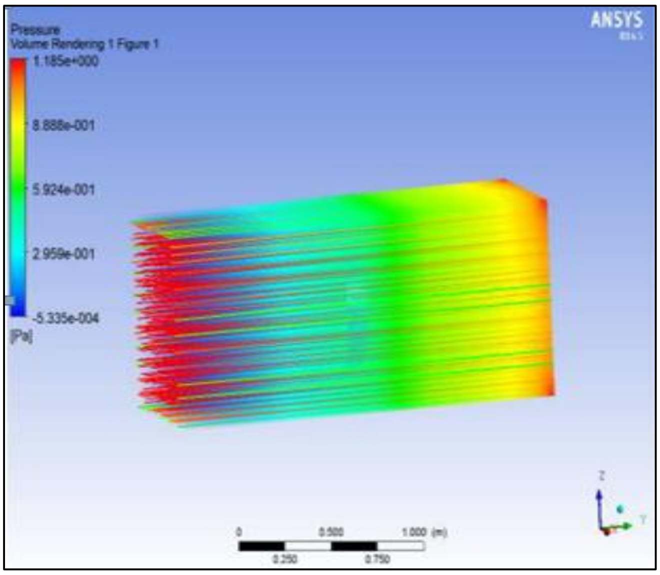

Fig. 17: velocity contour of straight diffuser without brim

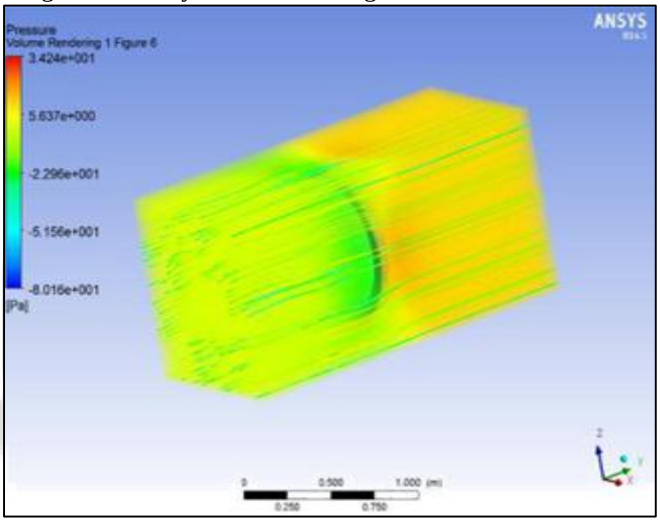

Fig.18: pressure contour of straight diffuser with brim

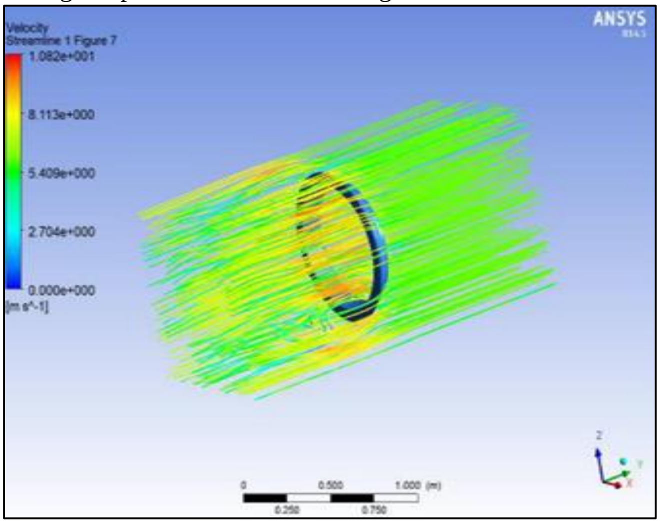

Fig.19: Velocity contour of straight diffuser with brim

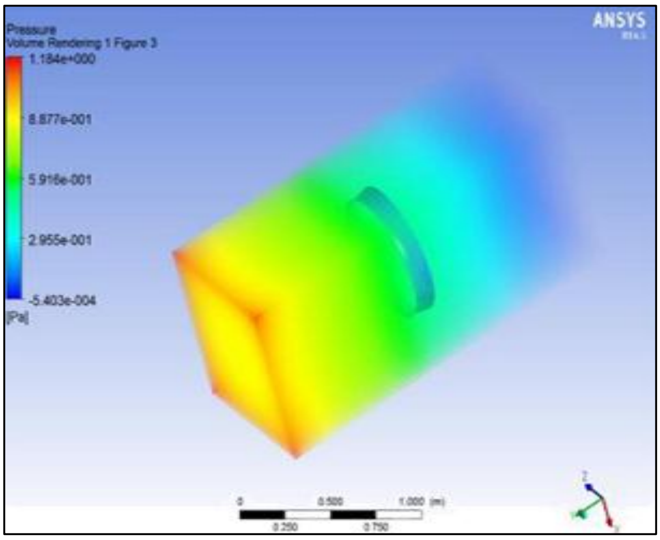

Fig. 20: Pressure contour of curved diffuser without brim

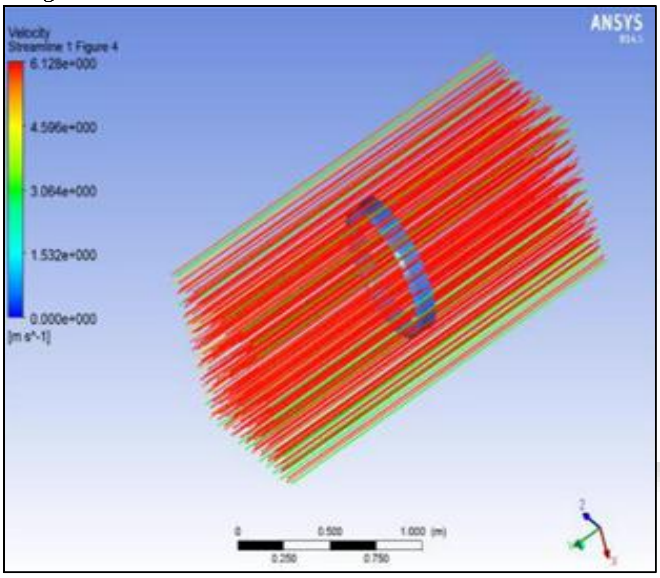

Fig. 21: Velocity contour of curved diffuser without brim

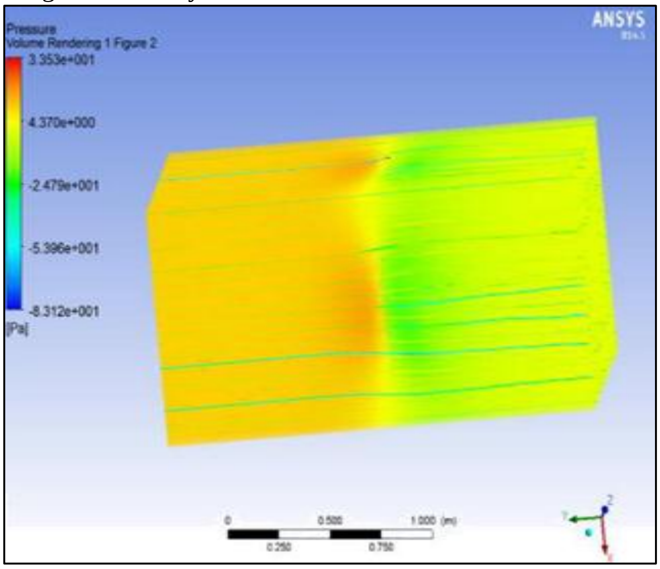

Fig. 22: Pressure contour of curved diffuser with brim

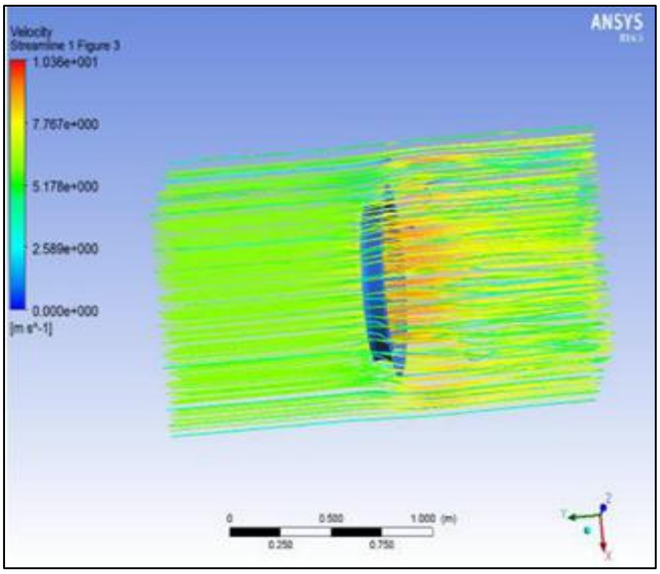

Fig. 23: Velocity contour of curved diffuser with brim

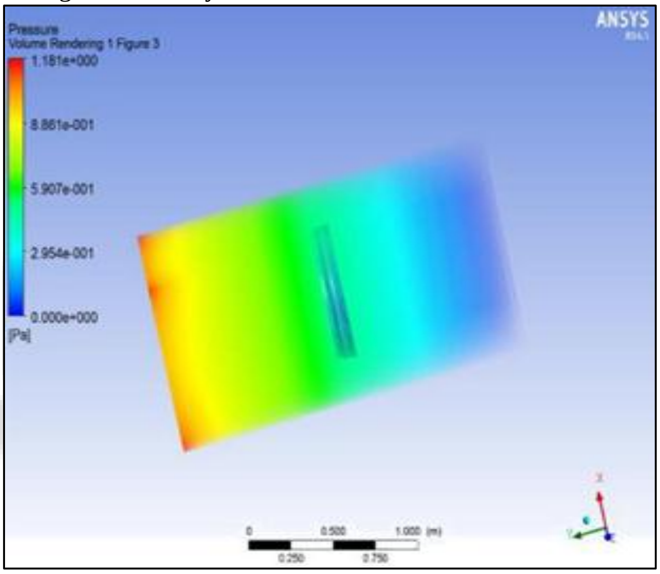

Fig. 24: Pressure contour of Stepped diffuser without brim

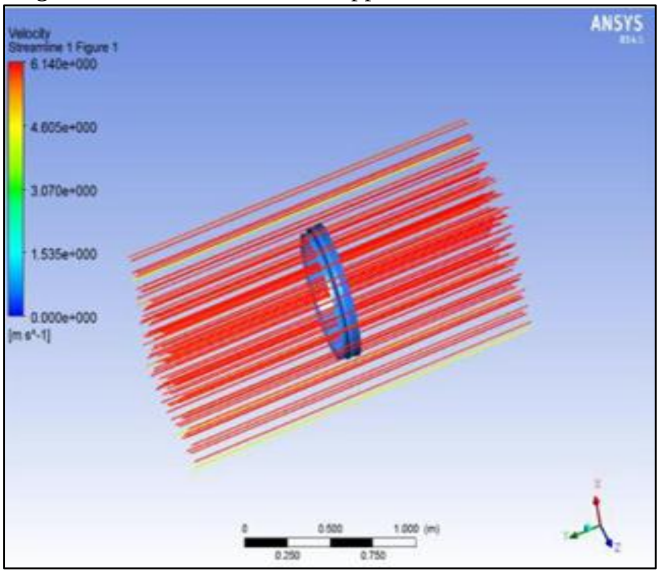

Fig. 25: Velocity contour of Stepped diffuser without brim

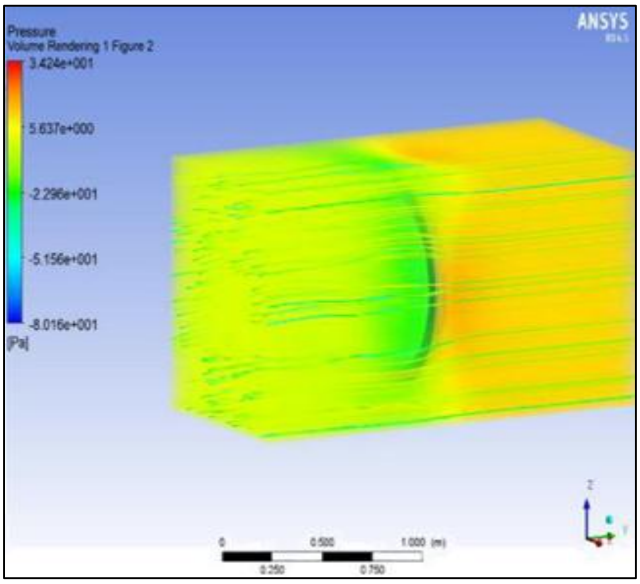

Fig. 26: Pressure contour of Stepped diffuser with brim

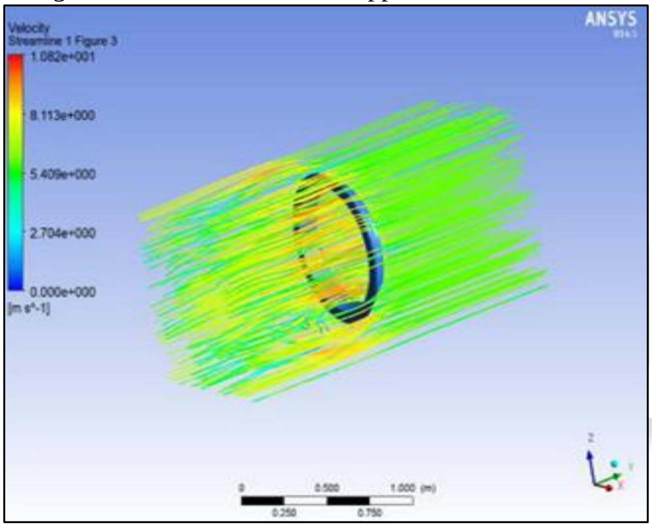

Fig. 27: Velocity contour of Stepped diffuser with brim

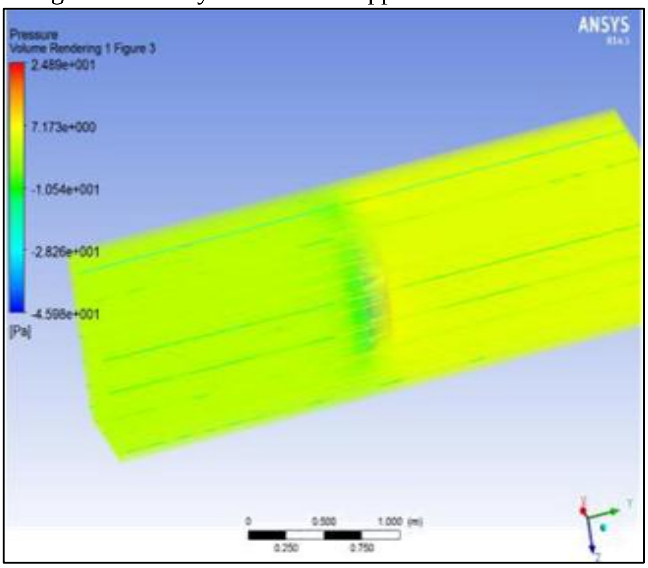

Fig. 28: Pressure contour of bumped diffuser without brim

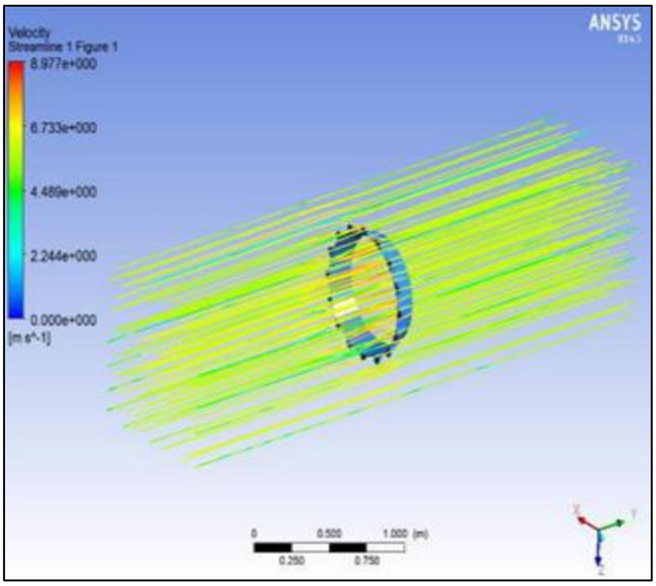

Fig. 29: Velocity contour of bumped diffuser without brim

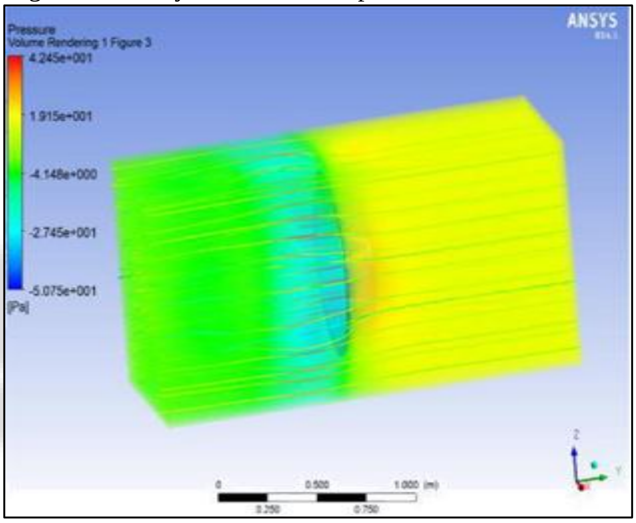

Fig. 30: Pressure contour of bumped diffuser with brim

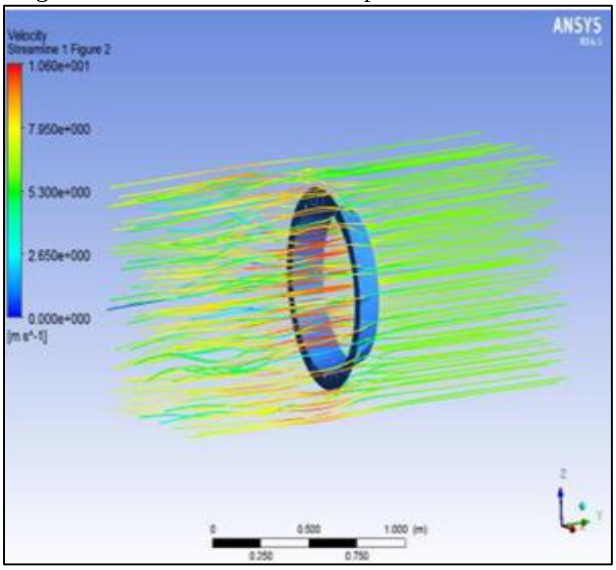

Fig. 31: Velocity contour of bumped diffuser with brim

XI. RESULT TABLE

Turbine	Pressure drop across difuser (N/m2)	Velocity (m/s)			Power (Watt)
		I/P	center	O/P	CpρAv3
Bare wind turbine	1	6	6.1	6.2	19
Straight without brim	1.181	6	6.5	6.18	22.23
Straight with brim	104.49	6	9.99	10	80.96
Curved without brim	1.181	6	6.6	6.19	24
Curved with brim	116.65	6	10.36	11.2	90
Stepped without brim	1.181	6	6.5	6.18	22.23
Stepped with brim	114.1	6	10.82	11.6	102.56
Bumped without brim	70.87	6	8.977	9.12	58.57
Bumped with brim	93.2	6	10.6	10.9	96.43

XII. RESULT & DISCUSSION

From above result table this is concluded that when we applied the diffuser on bare wind turbine, it will produces lower pressure region behind the wind turbine. Due to this lower pressure region more mass flow rate is occurred. Also it will produce high power output than bare wind turbine.

If we compare the diffuser without brim & diffuser with brim, it will show that diffuser with brim will produce more vortex formation than without brim.

Also stepped diffuser with brim will produce 5 times more power output than bare wind turbine. Bumped diffuser without brim will shows increase power output by 3 times more than the bare wind turbine. Also it shows the higher power output than other diffusers without brim.

From above discussion we conclude that stepped diffuser is more efficient than all other diffusers.

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