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Performance Investigation of Diffuser Augmented Wind Turbine

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Abstract

Renewable energy resources are becoming an increasingly important part of our total energy demands due to the depletion of fossil fuels and the emergence of global warming. Wind turbines are one type of renewable resource that is very usual in the offshore site has a stronger and steadier wind speed which can produce more energy. It is a fact that wind power is the best dilute and unpredictable source of energy that works with efficiency of great importance in the conversion of this energy to electricity. It is a common practice to place wind turbines on ridges and hills to increase wind velocity over that of free stream. If a device (shroud) can be added to a bare turbine to increase wind velocity just as our research was to add shrouds by means of computer simulations to encase the "bare turbine" thereby increasing efficiency. Our goal is to find a particular shroud that maximized air mass flow through the turbine beyond the best bare turbine operational conditions. In this analysis we have used CFD(Computational fluid dynamics) software 15.0 five case studies have been analyzed viz. (i) simulation of simple bare turbine (ii) 10 degree diffuser augmented wind turbine (iii) 20 degree diffuser augmented wind turbine (iv) 30 degree diffuser augmented wind turbine (v)) 40 degree diffuser augmented wind turbine Analysis shows that power generated by the turbine is maximum when Renewable energy facilities generally require less maintenance than traditional generators. Their fuel being derived from natural and available resources reduces the costs of operation.

Keywords—wind turbine, renewable energy, global warming, power

INTRODUCTION

Globalization, due to advancements in technologies and dependency on gadgets of human being is excessive such that consumption of electric energy is increased. In the present scenario fossil fuel and nuclear energy is used for the electric generation across the world. But this source of energy emits harmful gases and radiation which results pollution in our environment. Therefore renewable energy is future generation of electric energy because these energy is environment friendly and in exhaustive. Over more than 104,426 0 TW•h/year of world produces renewable energy resources out of India produces 5% and on the leading china produces 1,300.0 TW•h/year (terawatt-hours per year)

A wind turbine is a device that converts the wind's kinetic energy into electrical power. Wind turbines are manufactured in a wide range of vertical and horizontal axis types. The smallest turbines are used for applications such as battery charging for auxiliary power for boats or caravans or to power traffic warning signs. Slightly larger turbines can be used for making contributions to domestic power. Renewable energy and are used by many countries as part of a strategy to reduce their reliance on fossil fuels. Renewable energy has become an important topic in recent years because of how fossil fuels affect the environment and how they're being used faster than they are created. One major form of renewable energy is wind. Wind power is growing at a rate of 30% annually, so increasing the potential of the windmill is very important.

The current design of the windmill turbine has three large blades that spin slowly, which spins a shaft, which is connected to a gearbox to increase the rotational

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speed. Some torque is lost through the use of a gearbox. By increasing the rotational speed of the wind turbine, the gearbox and its torque losses can be eliminated from the design. Using higher density and smaller turbine blades allows for higher rotational speeds and a lower cut-in speed than the current low density three blade design. A venturi-like shroud will be placed around the turbine blades, increasing the velocity of the fluid where the pipe diameter decreases. This combination of a smaller, high-density blade and a venturi-like shroud allows for more power to be generated at any given wind speed and eliminates the need for a gearbox.

A Diffuser-Augmented Wind Turbine (DAWT) is a wind turbine modified with a cone shaped wind diffuser that is used to increase the efficiency of converting wind power to electrical power. The increased efficiency is possible due to the increased wind speeds that the diffuser can provide. In traditional bare turbines, the rotor blades are vertically mounted at the top of a support tower or shaft. In a DAWT, the rotor blades are mounted within the diffuser, which is then placed on the top of the support tower. Additional modifications can be made to the diffuser in order to further increase efficiency.

Design Most designs includes a cone shaped diffuser with the purpose of increasing the velocity of the air as it travels through the turbine. In order for this to be possible, the exit hole of the diffuser must be larger than the entrance hole to properly diffuse the air. As wind flows through the diffuser, it travels along the walls, which causes the exiting wind to form vortices of wind when exiting. These vortices cause most of the air to be diffused away from the centre of the exit, which creates a low pressure segment of air behind the turbine. The pressure difference accelerates the high pressure air in the front towards the low pressure air in the back, causing a significant increase in speed. If the diffuser were to instead have an exit hole smaller than its entrance, then the opposite effects would be achieved. A high pressure area would be formed at the exit, which would severely restrict airflow through the diffuser. Additional designs take the basic diffuser and make additional modifications in order to further increase power generation.

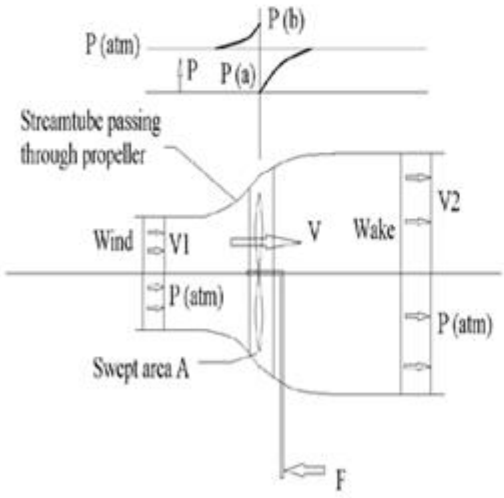

Figure 1.1-Betz steam tube analysis of power extraction from a wind mill

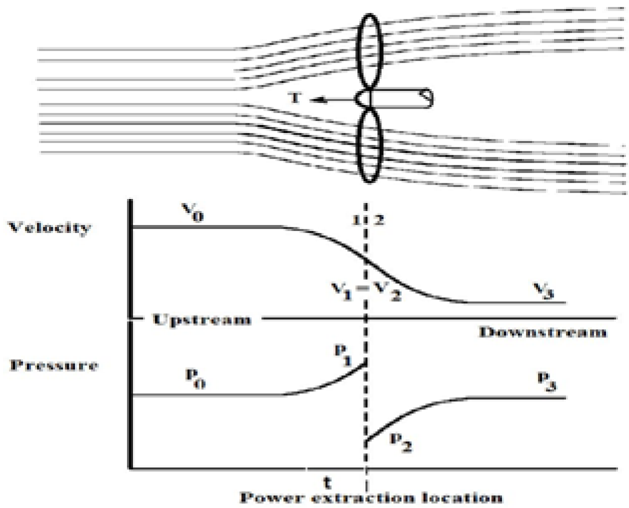

Fig 1.2- pressure and velocity curve

The ideal, frictionless efficiency of a propeller (horizontal axis wind turbine, HAWT) was predicted by Betz in 1920. The propeller is represented by an actuator disk, which creates across the propeller plane a pressure discontinuity. The wind is represented by a stream tube of approach velocity V1 and a slower downstream wake velocity V2 (Fig. 1). The pressure rises to Pb just before the disk returning to free stream pressure in the far wake

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and drops to Pa just after. A force F is needed to offset the wind pressure on the propeller.

The maximum available power to the propeller is the mass flow through the propeller times the total kinetic energy of the wind.

$$\text{Power available} = \frac{1}{2}\dot{M}\,[V_1]^2 \;\ldots\ldots\; (1)$$

We know that,

$\dot{m} = \rho\, A\, V_1$

Put this value in eq. 1

$$\text{Power available} = \frac{1}{2}\rho\, A\, [V_1]^3$$

Where,

$\dot{m}$ = mass flow rate

ρ= air density

A = swept area of blade

From the work of Betz, the maximum possible efficiency of an ideal frictionless wind turbine is usually stated in terms of the power coefficient C_P:

$$C_p = \frac{POWER}{\frac{1}{2}\rho A(V_1)^3}$$

$$C_{P_{max}} = 0.593$$

As stated in the abstract, efficiency is of great importance for the generation of electricity from wind power since the wind is a dilute source of energy. It is a common practice to place wind turbines on ridges and hills to increase wind velocity over that of free stream. If a device (shroud) can be added to a bare turbine to increase wind velocity just as the topography as mentioned above, then efficiency can be increased. Since power available in the wind is proportionate to the cube of wind velocity, small gains in wind velocity can mean large gains in shaft power. The diffuser shroud is one such device to increase wind velocity over that of free stream. A diffuser (conic section) increases the velocity of the airflow (wind velocity) through it. This increase is due to the effect of a region of sub-atmospheric pressure downstream of the diffuser , a condition unlike that of a ducted diffuser (i.e. airflow on inside only, with the goal of increasing pressure downstream). Nozzles likewise increase the velocity kinetic energy of a fluid. This is accomplished with a concurrent decrease in pressure, and a favorable gradient, which discourages wall separation of the fluid. The Bernoulli equation gives more favorable result due to this fact However, in our case; we have fluid flow through and around the nozzle. In this paper, we propose to model and analyze, by means of computer simulations, horizontal axis wind turbines (HAWT) with propeller type blades with the addition of various nozzle and diffuser shrouds encasing the bare turbine to increase shaft power for a given wind velocity of 20 m/s and a given turbine angular velocity of 60 rpm. As mentioned, the diffuser is a conic section that increases wind velocity above that of the free stream velocity.

With the nozzle shroud configuration, this is not the case. In fact, the free stream wind velocity is somewhat diminished, as will be shown later in this paper. We will also investigate a special “Stream tube” shaped shroud. Lastly, we will investigate the effect of turbine rpm for a given shroud and a given free stream wind velocity of 20 m/s on shaft power. Therefore, we shall focus on the diffuser/nozzle design encasing the turbine rather than on the turbine design itself (the turbine design is not changed in our simulations).

Literature review

A detailed discussion is carried out on wind renewable energy system considering enlisted According to Van Holten (1981) and Dics[1] (1986), augmentation means increasing the mass flow of air and mixing of turbulence with external flow. A conference was held in the year 1979 in USA based on DAWT. Due to diffuser assembly the power output can be augmented, but the cost of shrouded type turbine increases due to the complexity in design. According to Kogan et al. (1962 &1963) power output is a function of the rotor disc loading, diffuser inlet and exit pressure [2, 3]. In their analysis, the diffuser was characterized by the exit to the entry area ratio of 3.5. Moeller [4] et al. (2008) of Clarkson University also proposed diffuser augmented wind turbine (DAWT). The investigation concludes that the power output of DAWT is 4.25 times more than the power produced by conventional wind turbine. High output from the turbine is expected because of placing a diffuser at the outlet of the turbine to control the flow rate of air producing at Sub -atmospheric pressure. Moeller analyzed Clarkson's wind tamer, also. Thus, the power coefficient of wind mill can be increased to 0.5 from 0.39 when compared to conventional wind turbine. The low static pressure induces greater mass flow of air through the turbine in contrast to a conventional turbine design of the same diameter. The analysis is based on two diffuser design concepts. One is directed toward the unconventional, extremely small and cost effective configurations. This approach is based on the active external wind, to prevent separations of the diffuser internal boundary layer.

Another concept used high lift airfoil contours for the diffuser wall structure. Test results show that the power produced by DAWT is almost two times the power produced by conventional wind mill. Moeller concluded that the DAWT configuration is found to be cheaper than conventional wind mill for rotor diameters between 50 m and 20 m.

The optimum design of diffuser is incorporated in the analysis. Gilbert [6] et al. (1978) contributed efforts in connection with the company vortex energy, New Zealand. The experimental results are compared with the CFD analysis of Flay [7] et al. (1999) According to Flay the maximum power coefficient is 1.0. But according to Vortec.

A potential increase in efficiency that diffuser devices produce in wind turbines, particularly for small wind turbines. Numerous investigations relative to Diffuser Augmented Wind Turbine, DAWT, shrouded wind turbines concept over the last century were done .As reported by Ten Hoopen (2009), Betz (1929) was the first to acknowledged the potential of ducted/diffuser wind turbines. The idea of DAWT in a preliminary study was proposed again by Lilley et al. (1956). The work from Lilley et al. (1956) the increase in axial velocity and reduction of blade tip losses was described as been as the main factors to enhance the power. A creation of a flow augmentation was also suggested, where lying of a flap at diffuser exit plane would raise the power augmentation. As described by Phillips (2003), Lilley et al. (1956) regarded the cost of ducted windmill energy devices and suggested that one enhance of gain in power of at least 65 %relative to conventional wind turbines is achievable.

Energy Company the maximum power coefficient is significantly less than Betz limit. Philips7 (1999) submitted a thesis to University of Auckland based on the concept of diffuser Augmented wind Turbines.

Oman [8] et al. (1978) studied the fluid flow through diffuser augmented wind turbine. Pressure and velocity variation through the cross section of DAWT is discussed in the article. Lift and drag on the blade of diffuser augmented wind turbine is studied by Phillips7 et al.(2008). Igra[9] (1984) submitted a research paper on shrouded wind turbines in the Energy Conference EWEC 84, held in Hamburg. Igra compared the conventional wind mill and shrouded wind turbine. Hansen[10] et al. (2000) studied the efficiency of a horizontal axis wind turbine by using the diffuser around the rotor using CFD. According to Hansen the power coefficient can exceed Betz limit, through mass augmentation. Wele[11] et al. (2008) conducted experiments on duct type water and wind turbines. The augmentation of power is discussed in their research.

Van Bussel [12] (2007) studied the effect of torque in the rotor of a wind turbine using a diffuser round the rotor. Abe [13] et al. proposed the concept of flanged diffuser geometry in various articles. Metins[14] (2006) published a thesis on nozzle concentration effects for buildings with diffuser augmented wind turbines. The research of Bussel [15] concludes that low back-pressure and high diffuser exit area are highly beneficial. In the investigation, the optimal pressure drop is 8/9 of local dynamic pressure and is equal to the pressure drop of bare wind turbines without mass flow augmentation. According to Gerard, the augmentation factor 3.0 cannot be achieved. Vries [16] (1979) developed a theoretical model using diffuser augmented wind turbine. The negative back-pressure obtained in the earlier experiments is used in the analysis.

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Wind energy

In addition, wind turbine also generates electricity without creating pollution and it is well suited for isolated places with no connections to the outside grid [17].Yang et al. tried to optimize the capacity sizes of different components of hybrid solar-wind power generation systems employing a battery bank [18]. Similar exercise has been performed by Xing et al. by calculating the system optimum configurations by considering some decision variables included in the optimization process [19]. Daud and Ismail proposed a hybrid renewable system to solve power-supply problem for remote and isolated areas far from the grids [20]. This system consists of wind-solar system along with diesel engine to accomplish or to recover the load requirements . Similar exercise is done by Ismail et al., where sensitivity analysis was undertaken to evaluate the effect of change of some parameters on the cost of energy [21]. The results indicated that the optimal scenario is the one that consists of a combination of the PV panels, battery bank and a diesel generator and powering a rural house using this hybrid system. Mainly, wind energy was used at the peak demand time.

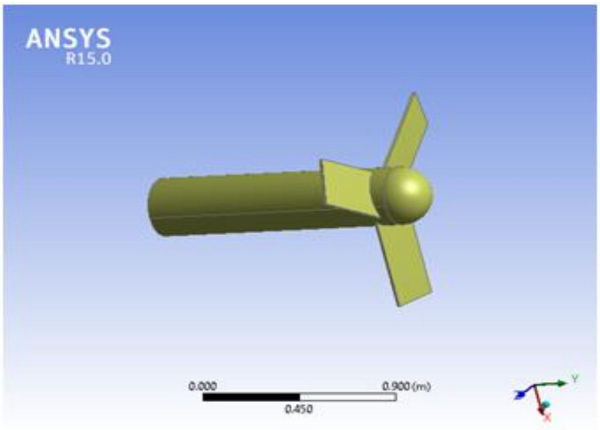
Experimental investigation

Dimensions of geometry

The following geometry for the bare and shrouded turbine:

Length of bare turbine – 1.2 m
Outer dia - 1.2 m
Width – 0.305 m
Fillet – 8 inch or 6 inch
Fan – 0.9 m
Thickness – 1 inch
Angle - 10^0
Shaft dia – 0.305 m

Another specification of shrouded wind turbine
Dia – 1.2 m (straight portion
Length – 1.2 m
Outer dia 1.8 m
Length – 1.2 m
Thickness of outer dia – 2 inch



Fig,1.3 Bare turbine

We enclose the turbine between two planes (a cylindrical disk). Free stream air is passed over the blades at 20 m/s. Wind velocity (axial component vector only), and pressure averages are computed by the function generator in the ANSYS software for the upstream plane and the downstream plane. Other parameters can also be calculated at any location on the model. The average velocities at each plane are used to calculate available power in the wind stream at each plane (the difference between the two is the POWER to turbine) turbine case. Note the velocity at the entrance to the shroud is only 14.24 m/s.

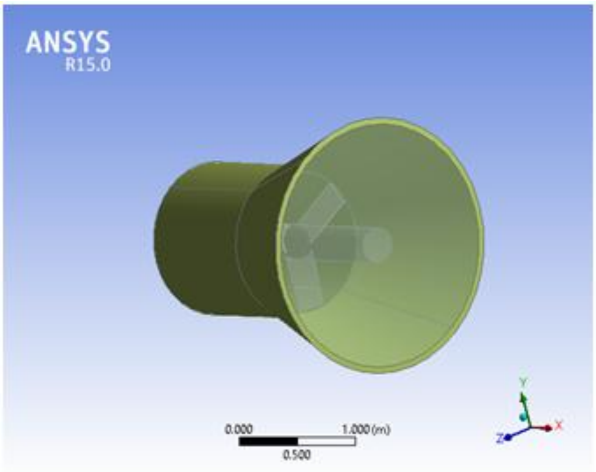


Fig. 1.4 Diffuser shroud turbine

Result

Accordingly, for our four feet diameter turbine (Area, A = 1.35 m2) and Velocity V1 = 20 m/s, the maximum available power from the wind is 6.9 kW.

Recall from Betz's work that the maximum theoretical value of Cp = 0.59, so that the power output of our turbine = 0.59(6.9 kW) = 4.07 kW if it were a "perfect" machine. From available charts [2] we see that our simple turbine might possibly have a Cp = 0.2 (American multiblade, which approximates our simple turbine, with speed ratio = 0.18). This results in an anticipated power output of 1.38 kW. We shall see if our computer simulation of our bare turbine in a free wind stream (20 m/s) and 60 rpm is close to this result.

SIMULATION OF BARE TURBINE

The average velocities at each plane are used to calculate available power in the wind stream at each plane (the difference between the two is the POWER to turbine). The results for the free turbine above are as follows: average velocity in = 18.78 m/s, average velocity out = 17.05 m/s, average pressure in = 101045 Pa, average pressure out = 100924 Pa, yielding a power of 1.61 kW. This result compares favourably with our theoretical power output of 1.38 kW. We will compare this output to commercially available turbines on a kW/m^2 (windswept area).

Diffuser Shroud Simulations

For 10 degree

In our next case, we increased THETA to ten degrees in the downstream half of our diffuser

The following results were obtained: average velocity inlet = 16.51 m/s, average velocity outlet = 9.86 m/s, inlet area = 1.35 m^2, outlet area = 1.73 m^2 resulting in maximum theoretical

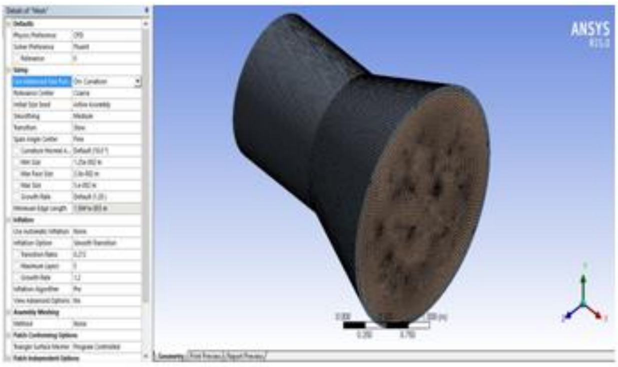


Fig4.2 – Representation of Meshing

Shaft power of 1.49 kW, a marked improvement over the THETA =10 degree case.

For 20 degree:

Next, we increased THETA to 20 degrees with the following results: average velocity inlet = 16.54 m/s, average velocity outlet = 6.91 m/s, area inlet = 1.35 m^2, area outlet = 2.28 m^2 resulting in shaft power = 2.17 kW, a large improvement over the THETA = 20 degree case.

For 30 degree:

We continued to increase the angle THETA to thirty degrees with the following results (Fig. Shows typical simulation): average velocity inlet = 16.01 m/s, average velocity outlet = 4.97 m/s, area inlet = 1.35 m^2, area outlet = 3.00 m^2 resulting in shaft power = 1.98 kW. We notice the beginning of a downward trend in POWER as a function of THETA.

For 40 degree:

To see if this downward trend continues, we increased THETA to forty degrees. We obtained the following results: average velocity inlet = 15.97 m/s, average velocity outlet = 8.76 m/s, area inlet = 1.35 m^2, area outlet = 3.57 m^2. These values resulted in a power output of 1.35 kW.

We observe from our simulations a maximum value near THETA = 20 degrees. Further increases in THETA at this point are not necessary. A plot of POWER vs. THETA (diffuser case) will disclose that value of THETA at which theoretical shaft power is a maximum for our diffuser configurations.

Boundary Condition

Velocity at inlet- 20m/sec

Propeller speed- 60 RPM

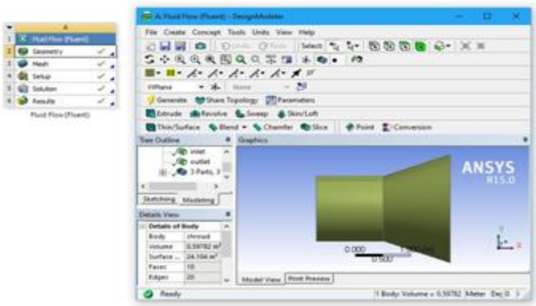


Fig4.1 – Geometry For 20^0 Diffuser Wind Turbine

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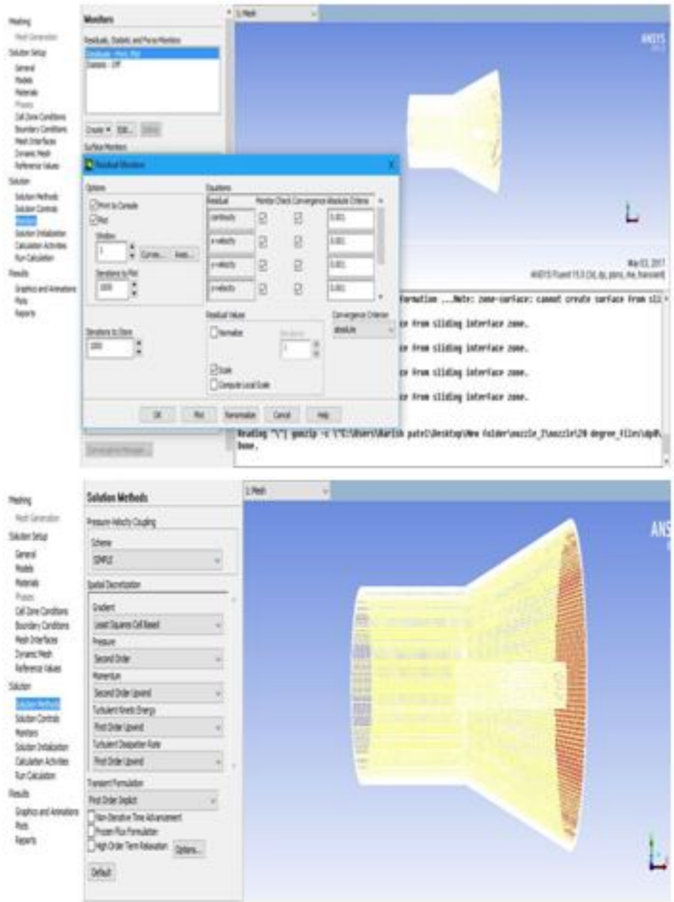

Fig 4.3- proceeding of working procedure in Ansys software

Simulation of Bare Turbine

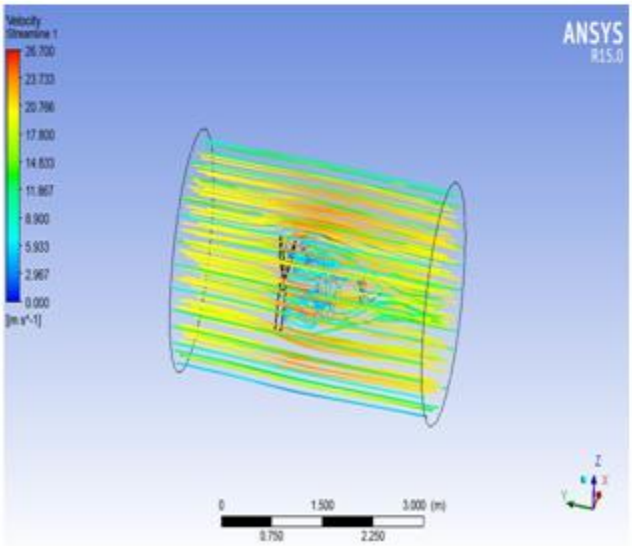

Fig.4.4: Results for Propeller with simple bare turbine

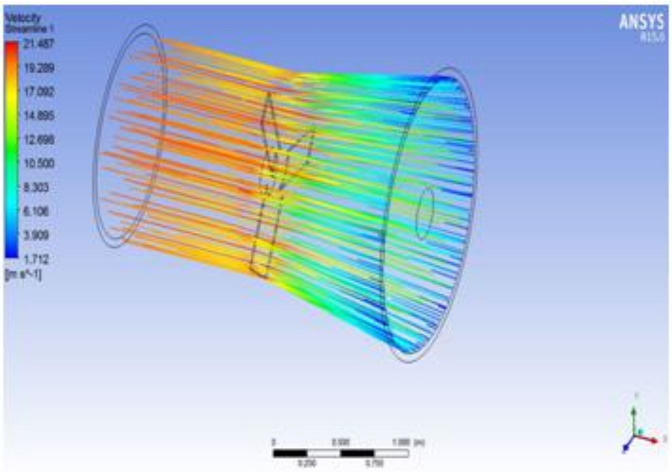

Fig 4.5:- Results for Propeller with diffuser Shroud Having Theta =10

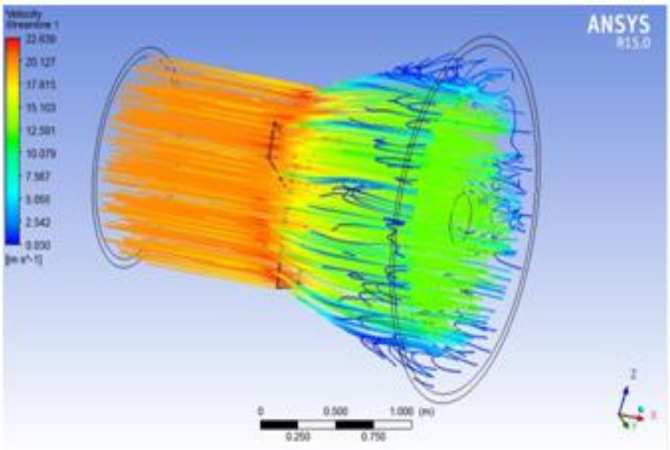

Fig 4.6:- Results for Propeller with diffuser Shroud Having Theta =20

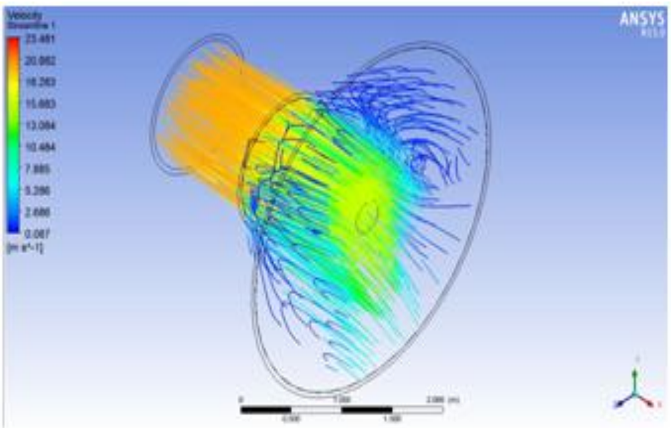

Fig 4.7:- Results for Propeller with diffuser Shroud Having Theta =40

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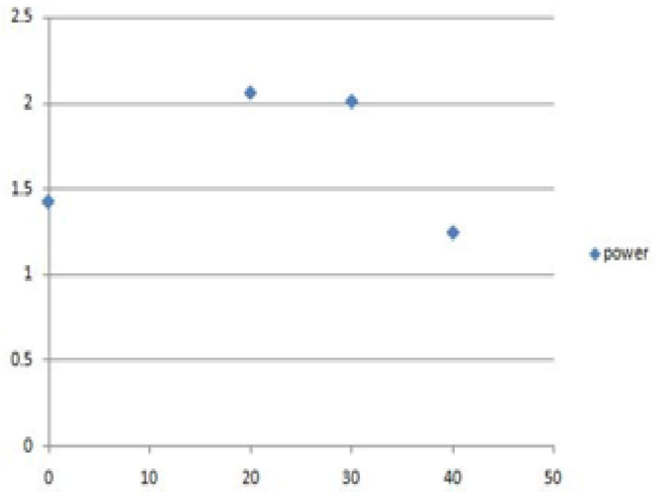

Graph between diffuser angle and power

Conclusion

Efficiency of wind power is mainly depend on velocity of the air and the blade design. so our main focus should be increase the air velocity with the help of shroud .in this thesis main objective was to consider Developing 3D model of diffuser section and turbine rotor with the solid work.

Analysis of model using ANSYS FLUENT 2015 Computational Fluid Dynamic (CFD) software. Perform the above analysis considering varying diffuser angle in order to find maximum power generation out of the same rotor. to fulfil objective ansys software used in this analysis during analysis following observation have been made-

- 10 degree diffuser case the power is increases in case of bare turbine.
- 20 degree diffuser case the power is further increases
- 30 degree diffuser case the power is slightly less as compare to 20 degree diffuser case
- Further increases the angle of diffuser is 40 degree at that condition the power is decreases continuously .it means that the efficiency is decreases For our particular turbine, maximum efficiency occurs at 25 degree diffuser angle at the power output of 2.23 kW (at the given wind velocity = 20 m/s).

Future Aspects

1) Making the shroud more streamlined (aerodynamic) than the simple shapes.
2) Combining the diffuser presented here with a much Comparison of some results with the future field measurements.
3) Diffuser device with different commercial wind turbines models implementing experimental and numerical tests;
4) Placing shrouds around other turbine configurations (for example a vertical axis wind turbine VAWT) to improve the Cp (coefficient of performance);
5) trying other ways to mount the shroud on the turbine body;

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