Theoretical & Computational Design of Wind Turbine with Wind Lens

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Abstract - *The power generated in a wind turbine is directly proportional to the cube of the wind speed as per theory. As per Betz limit, only 59.3% of kinetic energy is converted into power output by using wind turbine. If more wind energy is concentrated over the turbine blade then an effective increase in power output can be achieved. Thus, in order to achieve this a wind diffuser can be utilized which creates a turbulence behind turbine blades which draws more air into the turbine. This diffuser can effectively increase the energy output by increasing the speed of the wind turbine. The objective of work is to increase the reliability of turbine blades by developing airfoil structure and also to achieve reduction in noise during operation of the turbine.*

Key Words: **Betz Limit, Turbine Blade, Wind Diffuser, Turbulence**, **Airfoil**

1. INTRODUCTION

For effective energy resource in the future, the limitation of fossil fuel is known and security of alternative sources of energy has become important. Also due to environmental issues like global warming the development of alternative source of energy is imminent. Wind energy technologies are developing rapidly and are set to play a major role in the energy field in the future. But comparing the overall demand for energy, the extent of wind power usage is relatively small. Wind power generation is proportional to the cube of wind speed. 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. The diffuser creates a lower air pressure zone directly behind the blades, so as we know air will tend to move towards equilibrium the high-pressure air in the frontal side of the turbine will accelerate in to the low-pressure area at the caudal end of the turbine. It is also known and accepted that no turbine can produce a sustained and viable electric current at speeds below 10 mph. The wind lens creates an area of lower pressure behind the turbine thereby inducing a suction of wind through the turbine which increases the effective wind speed.

1.1 Working of Wind Turbine

Kinetic energy of moving air due to motion is utilized for the working of the wind turbine. When wind blows past the turbine blades., energy conservation takes place due to profile of the blades and the rotor rotates capturing the kinetic energy of the wind. Energy conversion from kinetic to mechanical energy takes place due to rotation of the blades. The blades are coupled to the rotor shaft and the shaft is further coupled to a step-up gearbox. The part of the turbine behind the blades which consist of the gearbox and generator is termed as Nacelle. The mechanical energy is converted into electrical energy by a generator giving power output. The nacelle is also equipped with wind vanes and anemometer. The anemometer is a wind speed measuring device and its main function is to measure high velocities i.e. greater than 10 m/sec. when the wind velocity is high the gearbox is cut off from the turbine to avoid any mechanical damages. Wind vanes are used to sense the change in the wind direction.
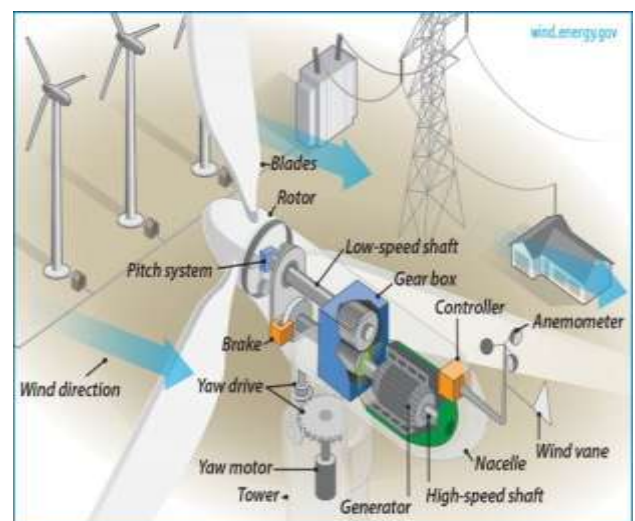

Fig-1: Working of a wind turbine

1.2 Wind Lens Turbine

Wind lens turbine is newly developed system which adopts a diffuser shaped structure along with a large flange attached at the exit of the shroud. Due to a strong vortex formation at the end of the flange, a huge amount of flow of mass can be drawn in to the turbine. Thus, this new system can exceed the Betz limit. Due to this the power developed by the turbine can be increased to a relatively greater amount.
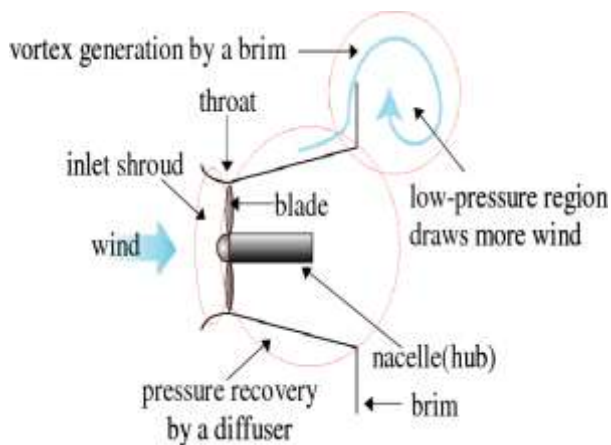

Fig-2: Flow around a turbine with wind lens

Fig-3: CAD Model of wind turbine assembly

2. LITERATURE REVIEW

We reviewed various studies carried out in field of wind engineering related to diffuser shroud.

Raju Govindharajan and Dr. K M Parammasivam conducted a numerical investigation and design optimization of brimmed diffuser which deals effect of low-pressure regions created by wind lens, and analyzed comparative numerical predictions of mass flow rates through the wind turbine with various types of wind lens to carry out torque augmentation.

Tushar Kunjir and C Limbadri conducted a performance analysis of wind turbine using wind lens technology in which they analyzed a simple brimmed ring structure which intentionally creates turbulence behind the turbine blades to draw more air flow in to the turbine. The structure effectively increases the speed of the turbine and thus leads to increase in power output.

3. DESIGN OF WIND LENS AND AIRFOIL

Following are the calculations for:

1) Airfoil
2) Wind lens

3.1 Airfoil

An airfoil shape when moved through a fluid produces an aerodynamic force. The component of the force which is parallel to the direction of the motion is called drag and the component which is perpendicular to direction of the motion is called lift. NACA 63(2)215

Profile was chosen due to the following reasons:

1) Simple Geometry
2) Effectiveness
3) Ease of Fabrication
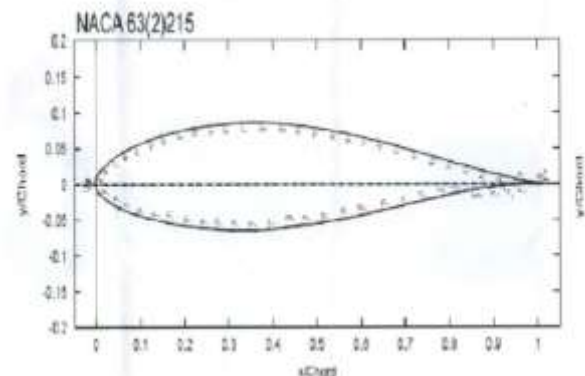4) High coefficient of lift

Fig-4: Airfoil Shape

Distance between the turbine is 5 to 9 times the rotor diameter in the direction of wind and 3 to 5 times perpendicular to the direction of wind.

From Betz Law,
No turbine can capture more than 59.3% of KE. The factor 0.593 is known as Betz coefficient.

Assume P=25 W
$P = 0.5 \ m \ v^2 \ C_p \ \eta_m \ \eta_o$
$25 = 30.3634 \ D^2$
D=0.9076 m
Tip Speed Ratio= 5 (for 3 blade turbine)
Also,
Tip Speed Ratio= $2\pi RN/v$
$\qquad$ N= $5 \ v/2\pi R$
$\qquad$ N= 8.80 rps
$\qquad$ N=528 rpm
Now,
$\qquad$ U= $2\pi RN$
$\qquad$ = 25.07 m/s

We Know That,

$$I = \tan^{-1}(v/U)$$
$$= 11.30^0$$

Pitch angle is generally considered in between 4 to 5. Therefore, assuming pitch angle 4.5^0.

$$\alpha = I - i$$
$$= 11.30 - 4.5$$
$$\alpha = 6.8099^0$$

3.2 Wind Lens (Shroud)

A shroud is designed with throat diameter of 1.1m with all other dimensions relative to the throat. It is a scaled down model of actual turbine with fan diameter of 45 cm, so turbine diameter must equal or be less than fan diameter. It is designed to create less obstruction to the air flow.

L=1.25D=1.1345m
L_s=0.75L=0.8508m
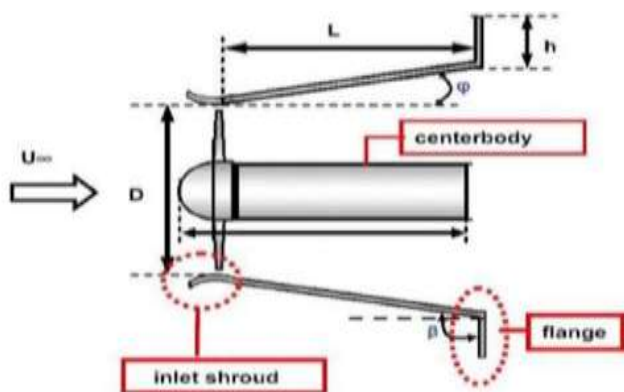D_h=0.22D=0.1996m
h=0.5D=0.4538m
ϕ=11.30^0
V=5 m/s

Fig-5: Schematic Diagram of Wind Lens with relative dimensions

Table 1- Constant Values and Symbols

Constant Values and Symbols			
Serial No.	Parameter	Symbol	Value
1	Average Air Velocity	V	5 m/s
2	Air Density	P	1.22 kg/m^3
3	Mechanical Efficiency	η_m	0.9
4	Overall Efficiency	η_o	0.95
5	Betz Coefficient	C_p	0.593
6	Pitch Angle	I	4.5^0

4. CFD Modelling

Steps Involved in CFD Modelling are:

1) The geometry (physical bound) of the problem is defined.
2) The volume occupied by the fluid is divided into discrete cells known as mesh. Mesh can be uniform or non-uniform.
3) Boundary Conditions are defined. This involves specifying the fluid behavior and properties at the boundaries of the problem. For transient problems, the initial conditions are also defined. v= 5 m/s where, v = stream line velocity of wind at inlet.
4) Simulation is started and the equations are solved iteratively as a steady-state using K-epsilon (k-ε) turbulence model.
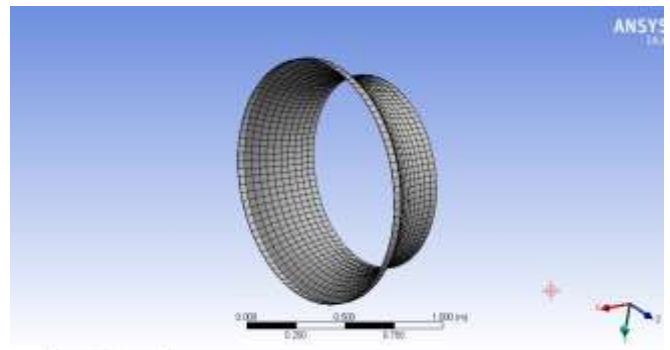5) Ultimately a post processor is used for the analysis and visualization of the solution.

Fig-6: Meshing of Wind Lens

5. CONCLUSION & SCOPE

Analytical calculations for Airfoil and wind lens were carried out. Computational Analysis of shroud shows significant increase in stream-line velocity which causes increase in power generation.

1) The stream-line velocity was found to increase from 5 m/s to 9 m/s

Taking v= 5m/s

We Know that,
$P = 1 \backslash 2 \, \rho \, A \, v^3 \, C_p \, \eta_m \, \eta_o$
$= 1/8*1.22*0.646*5^3*0.593*0.9*0.95$
$= 24.97$ W

Taking v= 9m/s
$P = 1/2 \, \rho \, A \, v^3 \, C_p \, \eta_m \, \eta_o$
$= 1/2 *1.22*0.646*9^3*0.593*0.9*0.95$
$= 145.65$ W

Table 2- Comparative Results

Comparative results		
Sr No	Velocity (m/s)	Power Output (Watts)
1	5	24.97
2	9	145.65

According to the above-mentioned calculations and comparative results we observe that the % increase in power generation is 82.85%.
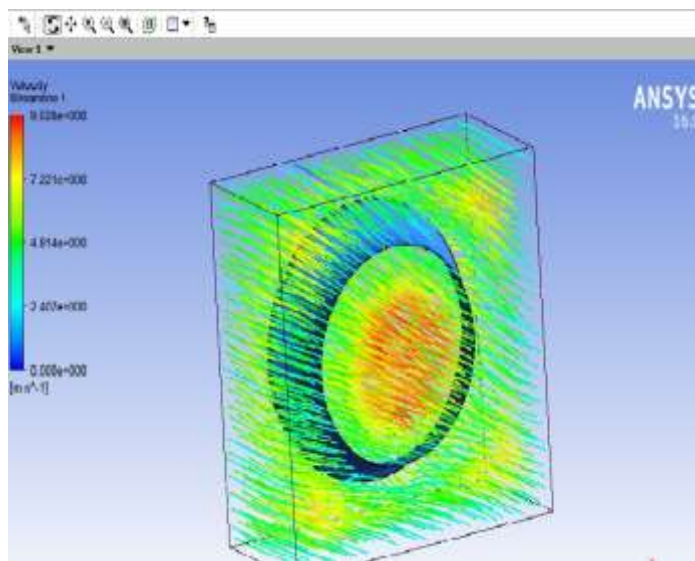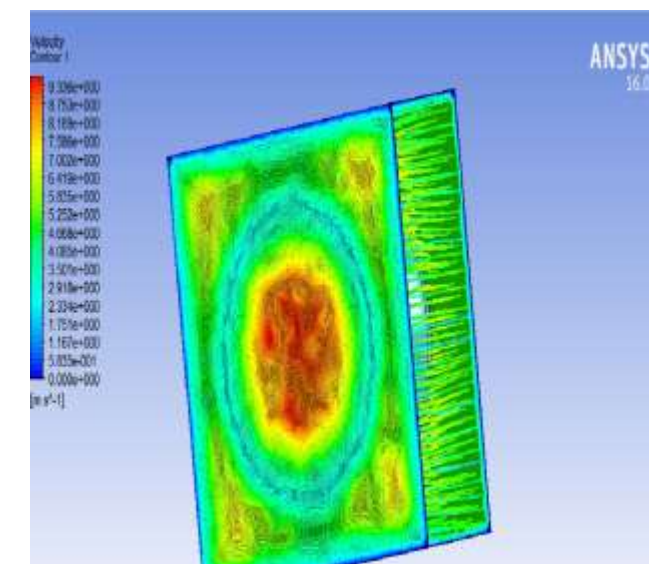

Fig-7: Result of Computational Analysis

Fig-8: Result of computational analysis

The above-mentioned conclusion will be experimentally validated by manufacturing prototype and also conducting experiment on the prototype by using above mentioned data.

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