Experimental Validation of Computational Design of Wind Turbine with Wind Lens

Sumukh Kulkarni[#1], Abhay Badhe[#2], Prashant Kumbhar[#3], Prem Panaval[#4], Rohit Jadhao[#5]

[#,1,2,3,4]*UG Student, Department of Mechanical Engineering, PCET's NMIET, Talegaon Dabhade, Pune, Maharashtra, India*

[#5]*Assistant Professor, Department of Mechanical Engineering, PCET's NMIET, Talegaon Dabhade, Pune, Maharashtra, India*

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. The objective of work is to increase the reliability of turbine blades by developing air foil structure and also to achieve reduction in noise during operation of the turbine. 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. If more wind energy is concentrated over the turbine blade then an effective increase in power output can be achieved.

Keywords — *Wind turbine blades, Aerofoil, Wind Diffuser.*

I. INTRODUCTION

For the application of an effective energy resource in the future, the limitation of fossil fuels is clear and the security of alternative energy sources is an important subject. Furthermore, due to concerns for environmental issues, i.e., global warming, etc., the development and application of renewable and clean new energy are strongly expected. 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. 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. This creates a lower air pressure within the area directly behind the blades. Because air will tend to move toward equilibrium, the high-pressure air in front of the blades will necessarily accelerates into the low-pressure area the wind lens working at lower wind speeds than traditional turbines.

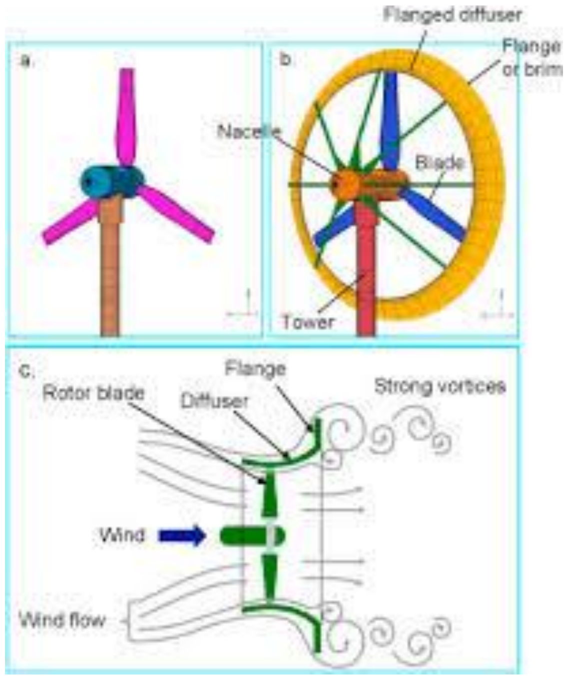

Fig 1: Wind Turbine with Wind Lens

II. 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.

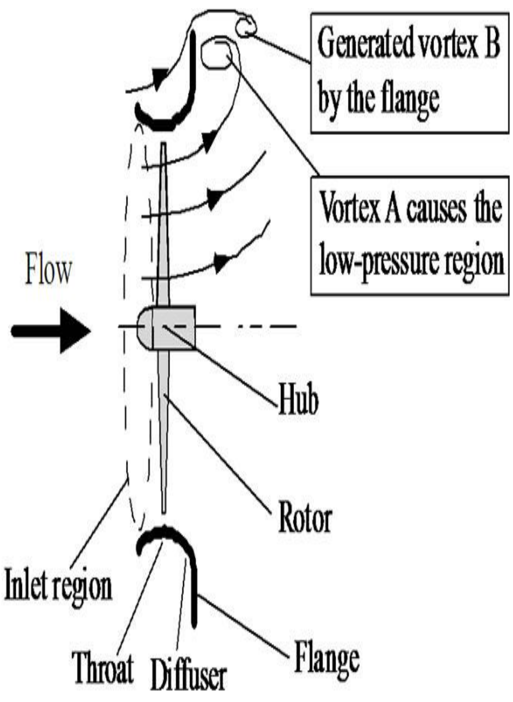

Fig 2: Working of Wind Turbine

A. *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. 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. The turbulence created as a result of the new configuration creates a low-pressure zone behind the turbine, causing greater wind to pass through the turbine, and this, in turn, increases blade rotation and energy output. Wind power is proportional to the wind speed cubed. If we can increase the wind speed with some mechanism by utilizing the fluid dynamic nature around a structure, namely if we can capture and concentrate the wind energy locally, the output power of a wind turbine can be increased substantially.

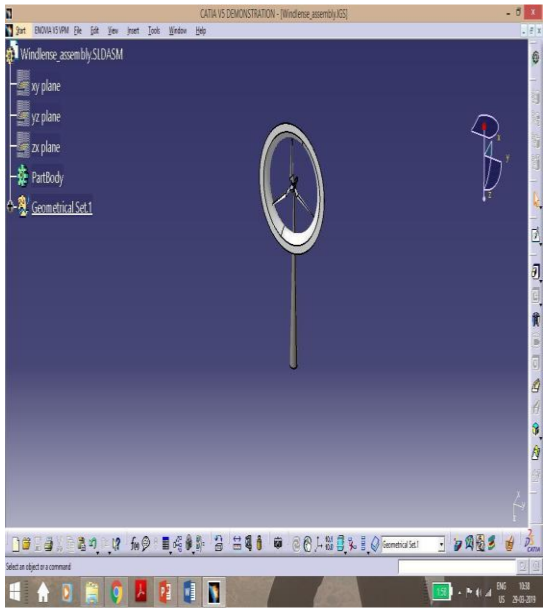

Fig 3: CAD Model of Wind Lens Turbine

III. LITERATURE REVIEW

We reviewed various research studies carried out in the field of wind engineering related to shrouded wind turbines.

A. Yuji Ohya and Takashi Karasudani designed a shrouded wind turbine that is equipped with a brimmed diffuser came. They call it the "wind-lens turbine". Next, they added an appropriate structure for entrance, called an inlet shroud, to the entrance of the diffuser with a brim. The inlet shroud makes wind easy to flow into the diffuser. Viewed as a whole, the collection-acceleration device consists of a venture shaped structure with a brim. The plate forms vortices behind it and generates a low-pressure region behind the diffuser. Accordingly, the wind flows into a low-pressure region; the wind velocity is accelerated further near the entrance of the diffuser.

B. Kenichi Abe, Yuji Ohya carried out numerical investigations for flow fields around flanged diffusers to develop small type wind turbines less than 1.5 kW. Comparison of the computed results with the corresponding experimental data is done. Furthermore, by processing the computational results, the input power coefficient is estimated under various conditions of diffuser opening angle and loading coefficient. It is shown that the performance of a flanged diffuser strongly depends on the loading coefficient as well as the opening angle because it greatly affects the nature of the separation appearing inside the diffuser. Their present investigation suggests that the loading coefficient for the best performance of a flanged diffuser is considerably smaller than that for a bare wind turbine.

C. Kazuhiko Toshimitsu, Taiga Arakane, Masatoshi Saiki, and Takuya Sato stated that the wind turbine with a flanged-diffuser shroud -so called "wind-lens turbine"- is developed as one of high-performance wind turbines by Ohya et al. In the paper, the wind turbine performance is presented for both steady and unsteady winds. As the results, the compact-type wind-lens turbine shows better performance than the only rotor in sinusoidally oscillating velocity wind. In order to make clear the relationship between flow field and the turbine performance, the specific flow fields are investigated by PIV.

IV. 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 behaviour and properties at the boundaries of the problem. For transient problems, the initial conditions are also defined. v= 5 m/s

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.

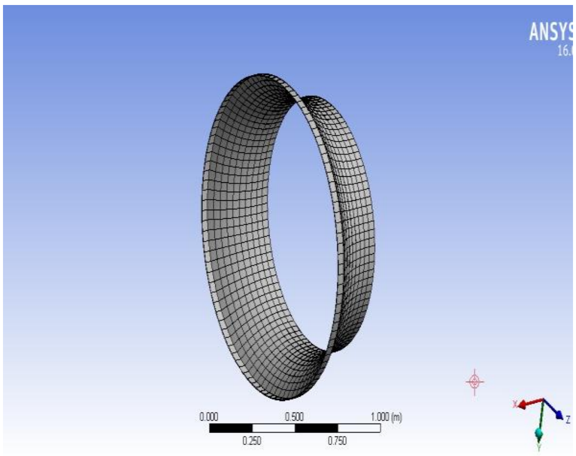

Fig 4: Meshing of Wind Lens

V. EXPERIMENTAL SETUP & PROCEDURE

A. *Components of Experimental Setup*

1) Rotor Blade: Based on NACA 63(2)215 airfoil shape. Manufactured using wood in carpentry shop. Firstly, raw material i.e. wood block was cut to a length of 0.35 meter and width of 0.07 meter and depth of 0.03 meter. Then the block was finished to obtain to obtain airfoil shape.

2) Hub: Aluminum rod of 50 mm diameter was cut to a length of 43 mm. Three holes of 28 mm diameter were bored to a depth 17mm for fixing of rotor blades. Also, three holes of 4 mm diameter were drilled for fastening purposes. A through hole of 10 mm diameter was bored for assembly of shaft and hub.

3) Wind lens: A square GI sheet of 12-gauge thickness was laser cut in to 3 circular arcs and spot welded together to form a wind lens of 0.75-meter ID.

4) Ball Bearings: Two deep groove ball radial ball bearings with 10 mm ID (6200) were used for support of rotor shaft and its frictionless movement. Also, a deep groove radial ball bearing with 15 mm ID (6202) was used for purpose of yawing to counter variable wind directions and improving wind- alignment capability of turbine.

5) Support Tower: A Mild Steel rod of 50mm ID was cut to a height of 1.61 meter and is used in the setup for support of Wind Lens assembly. 6202 ball bearing of 15 mm ID is used for yawing mechanism and is fixed on upper end of tower.

B. *Testing Procedure*

Firstly, we need to test the apparatus without wind lens.

1) For that we need to remove the wind lens from the rotor assembly.

2) Then we have to start the testing.

3) The fan is kept in front of the rotor assembly and the fan speed is kept at 6m/sec and this wind speed is measured by anemometer.

4)Then the rotor of the apparatus starts rotating at a certain speed.

5)This speed is measured using tachometer to get its rpm.

6)The wind speed is measured of the apparatus is measured on its both sides using anemometer properly.

7)After testing the apparatus without brim, we take readings for rotor rpm speed and wind speeds. Secondly, we test the apparatus with wind lens.

8)Wind lens is now attached to the rotor assembly apparatus.

9)Then again, we do the testing.

10)The fan is kept in front of the rotor assembly and the wind speed is measured by the anemometer.

11)Then the rotor of the apparatus starts rotating at a certain speed.

12)This speed is measured using tachometer to get its rpm.

13)The wind speed is measured of the apparatus is measured on its both sides using anemometer properly.

14)After testing the apparatus with wind lens, we take readings for rotor rpm speed and wind speeds.

15)Then the result is obtained from the readings taken for with wind lens and without wind lens and conclusions are drawn from it.

Fig 5: Experimental Setup

V. RESULT

we know that,

TSR = $2\pi RN/V$

where,

R= Radius of rotor

N= RPM

V= Wind Velocity

So,

$5 = (2 * \pi * 0.4538 * N) / 5$

Thus,

N=8.80 rps

So, N=528 rpm

Similarly, we calculated theoretical RPM for other wind velocities.

Sr. No.	Velocity (m/s)	Theoretical RPM	Experimental RPM	
			Without Lens	With Lens
1	4	424	385	416
2	4.5	478	404	439
3	5	528	428	497
4	5.5	583	473	511
5	6	636	506	534

Table 1: - Result Table

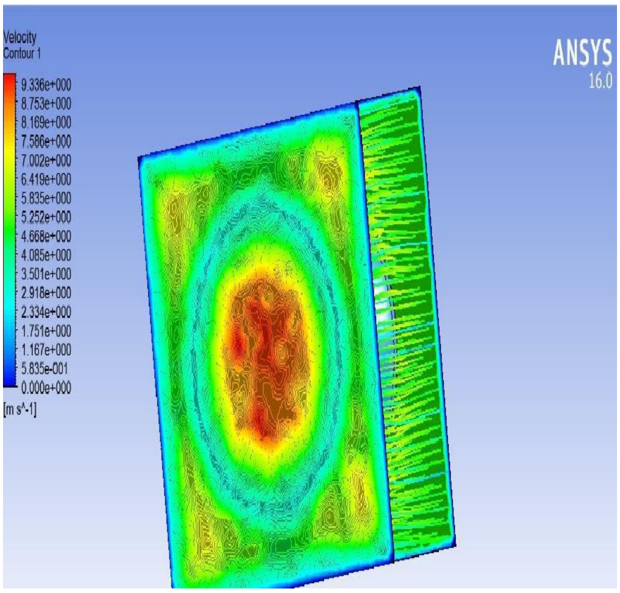

Fig 6: ANSYS Simulation Result

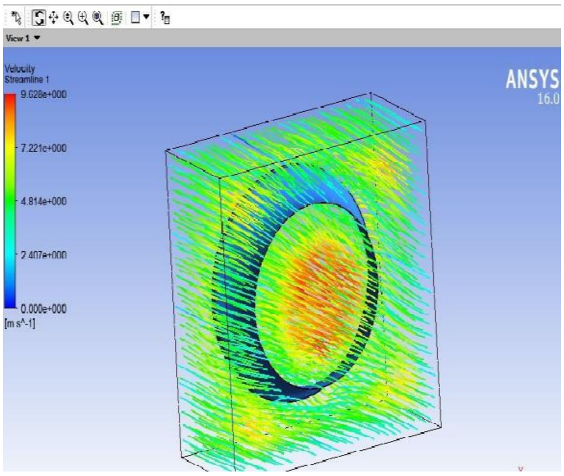

Fig 7: ANSYS Simulation Result

The streamwise velocity was found to increase from 5m/s to 9 m/s

Taking v= 5m/s

We Know that,

P= 1\2 ρ A v^3 Cp η_m η_o

= 1/8*1.22*0.646*53*0.593*0.9*0.95

= 24.97 W

Taking v= 9m/s

P= 1/2 ρ A v^3 Cp η_m η_o

= 1/2 *1.22*0.646*93*0.593*0.9*0.95

= 145.65 W

Sr No	Velocity (m/s)	Power (W)
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%.

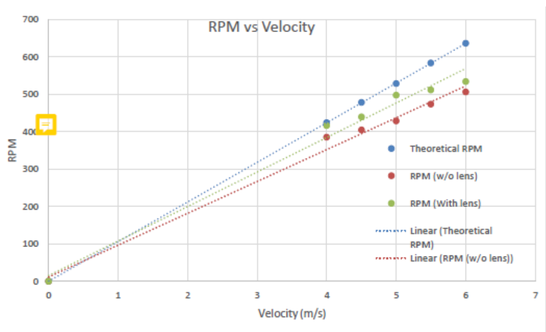

Fig 8 : - Plot of Velocity VS RPM

From the above graph following observations are made:

1) Graph shows that RPM is directly proportional to the streamline velocity of wind.

2) During the experiment, there were significant losses which explain the difference between theoretical and actual values of RPM.

3) Use of wind lens shows increase in RPM at various streamline velocities.

VI. CONCLUSION

In this study, friction is modelled to be proportional to the square of the velocity of the air crossing the wind turbine blades. Through the analysis it was observed that both the power coefficient and the thrust coefficient degrade with friction. Finally, plots were given to suggest ways of assembling wind turbines to gain more of wind power for each tower installation.

VII. REFERENCES

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