Issue 6 Volume 3 ISSN: 2321-8134

IJFEAT

INTERNATIONAL JOURNAL FOR ENGINEERING APPLICATIONS AND TECHNOLOGY

TITLE: Design and Fabrication of Wind Lens Technology

Pravin Mane[1], Sagar Mishra[2], Sanjay Kumavat[3] , Inzmam Mulla[4] ,Prof. Pinak Kapalay[5]

[1]Student, Mechanical Department, SKNSITS,Maharashtra,India,manepravin90@gmail.com
[2]Student, Mechanical Department, SKNSITS,Maharashtra,India,sagarmiishra@gmail.com
[3]Student, Mechanical Department, SKNSITS,Maharashtra,India,sankumavat44@gmail.com
[4]Student, Mechanical Department, SKNSITS,Maharashtra,India,inzamammulla6@gmail.com
[5]Assistant Professor, Mechanical Department, SKNSITS, Maharashtra, India, ppk.sknsits@sinhgad.edu

Abstract

We have developed a new wind turbine system that consists of a diffuser shroud with a broad-ring brim at the exit periphery and a wind turbine inside it. The shrouded wind turbine with a brimmed diffuser has demonstrated power augmentation for a given turbine diameter and wind speed by a factor of about 2-5 compared with a bare wind turbine. This is because a low-pressure region due to a strong vortex formation behind the broad brim draws more mass flow to the wind turbine inside the diffuser shroud. An optimum aerodynamic design method has been developed for the new type of wind turbine called "wind-lens turbine". The wind-lens turbine has a diffuser with brim called "wind-lens", by which the wind concentration on the turbine rotor and the significant enhancement of the turbine output can be achieved. The present design method is based on a genetic algorithm (GA) and a quasi-three-dimensional design of turbine rotor.

***Index Terms:* Wind turbine, Diffuser, Brim, Power augmentation, Wind tunnel experiment**

--- *** ---

1. Introduction

In recent years, wind energy has become one of the most economical renewable energy technologies. Today, electricity generating wind turbines employ proven and tested technology, and provide a secure and sustainable energy supply. At good, windy sites, wind energy can already successfully compete with conventional energy production. Many countries have considerable wind resources, which are still untapped. A technology which offers remarkable advantages is not used to its full potential such as:

1. Wind energy produces no greenhouse gases**.**

2.Wind power plants can make a significant contribution to the regional electricity supply and to power supply diversification.

3 .A very short lead time for planning and construction is required as compared to conventional power projects.

4.Wind energy projects are flexible with regard to an increasing energy demand – single turbines can easily be added to an existing park.

5. Finally, wind energy projects can make use of local resources in terms of labour, capital and materials.

The technological development of recent years, bringing more efficient and more reliable wind turbines, is making wind power more cost-effective. In general, the specific energy costs per annual kWh decrease with the size of the turbine notwithstanding existing supply difficulties. 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. In Japan, wind lenses are being researched by the Wind Engineering Section of Kyushu University. If we use a long type diffuser, the wind speed is accelerated further near the entrance of the diffuser. However, a long heavy structure is not preferable in the practical sense. Then we added a ring-type plate, called "brim", to the exit periphery of a short diffuser. 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. The present study aims at determining how to collect wind energy efficiently and what kind of a wind turbine can generate energy effectively from the wind.

Fig. 1: Wind lens

2. Technique

Selecting number of blades – Getting the exact number of blades for the operation is of greater importance to the efficiency that we get from the turbine. There are different theories that help us understand the exact number of blades that we might need to suit the particular design.

Aerofoil selection – After selecting the blades according the cost and efficiency the aerofoil section of the blade is of greater importance. The most important factor is availability and cost. Thus generally optimum aerofoil is selected to meet both the needs. There are a number of aerofoil profiles available but only few are suitable to the described wind conditions and meet the efficiency and cost needs.

Setting the output power – Based on the output requirements and applications taken into considerations the output power is selected. It is generally assumed comparatively higher than the requirements due to the losses.

Selection of material of each part – Material of each part should be selecting based on the strength and capacity. Material is one of the most important factors that affect the cost; hence it must be taken care of.

Wind velocity – The wind velocity for a particular region is given by the IMD department.

Rotor Diameter – We know the power torque and angular velocity relationship. Using this relationship along with Betz law and mechanical and electrical efficiency, rotor diameter is calculated. This diameter directly leads to the tower height.

Tip Speed Ratio (TSR) – Specified graphs are available to calculate the tip speed ratio based on number of blades. According to specified range the optimum value can be selected. Based on tip speed ratio number of rotations can be directly calculated also the local tip sped ratios can be calculated.

Angle of attack – Completing stressing on the blade geometry the angle can be calculated, hence the angle of attack can be calculated. Angle of attack for a blade should be in between 6-8o. Angle of attack is an important dimension as the lift and drag forces directly depends on it. Angle of attack directly influences the forces and twist which is also calculated after the angle of attack.

Lift and Drag Forces – These are the two main driving forces for the blade. Coefficients of lift and drag along with angle of attack and area helps us to calculate the forces. Lift forces should be maximum and drag forces should be minimum. After calculating the forces with the help of coefficients of lift and drag the chord lengths can be calculated.

3. Development of a Collection Acceleration Device for Wind (Diffuser Shroud Equipped with a Brim, it is called “wind-lens”)

3.1 Selection of a diffuser-type structure as the basic form

A large boundary-layer wind tunnel of the Research Institute for Applied Mechanics, Kyushu University, was used. It has a measurement section of 15m long × 3.6m wide × 2m high with a maximum wind velocity of 30m/s. Various hollow-structure models such as a nozzle, cylindrical and diffuser type were tested. The distributions of wind velocity *U* and static pressure *p* along the central axis of the hollow-structure model were measured with an **I** type hot-wire and a static-pressure tube. The experiments revealed that a diffuser-shaped structure can accelerate the wind at the entrance body.

3.2 Idea of a ring-type plate which forms vortices (It is called “brim”)

If we use a long type diffuser, the wind speed is accelerated further near the entrance of the diffuser. However, a long heavy structure is not preferable in the practical sense. Then we added a ring-type plate, called “brim”, to the exit periphery of a short diffuser. 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.

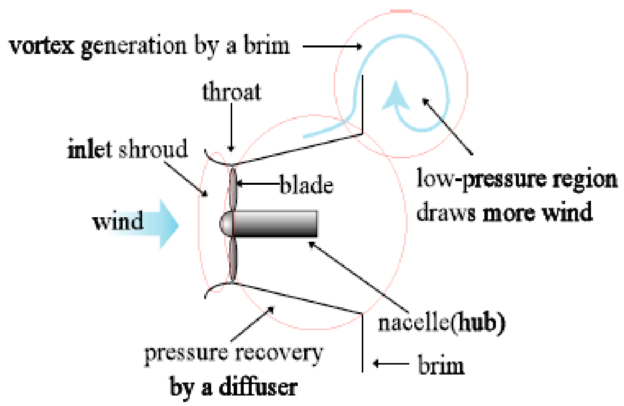

Fig.2 Flow around a wind turbine with wind-lens

Fig.2 illustrates the flow mechanism. A shrouded wind turbine equipped with a brimmed diffuser came into existence in this way. We call it the wind-lens turbine. Next we add 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 venturi-shaped structure with a brim. As for other parameters, we have examined the diffuser opening angle, the hub ratio, and the center-body length. Then the optimal shape of a brimmed diffuser was found. In addition, we are now examining the turbine blade shape in order to acquire higher output power. As illustrated in Fig.3, when a brimmed diffuser is applied (see Fig.4), a remarkable increase in the output power coefficient ($Cw=P/0.5\rho AU^3$, P: output power, A: swept area of a turbine blade) of approximately 4-5 times that of a conventional wind turbine is achieved in field experiment.

3.3. Characteristics of a wind turbine with brimmed diffuser shroud

Fig.4 shows the first prototype of a wind turbine equipped with a brimmed diffuser shroud (rated power 500W, rotor diameter of 0.7m). The diffuser length of this model is 1.47 times as long as the diameter of the diffuser throat D (Lt =1.47D). The width of the brim is h=0.5D. The important features of this wind turbine equipped with a brimmed diffuser shroud are as follows.

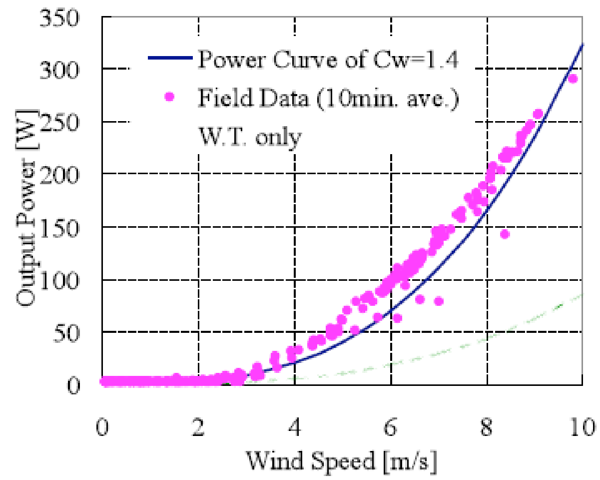

Fig.3 Field experiment of 500W wind turbine with wind-lens

1) Four-fivefold increase in output power compared to conventional wind turbines due to concentration of the wind energy (“wind-lens” technology).

2) Brim-based yaw control: The brim at the exit of the diffuser makes wind turbines equipped with a brimmed diffuser rotate following the change in the wind direction, like a weathercock. As a result, the wind turbine automatically turns to face the wind.

3) Significant reduction in wind turbine noise: Basically, an airfoil section of the turbine blade, which gives the best performance in a low-tip speed ratio range, is chosen. Since the vortices generated from the blade tips are considerably suppressed through the interference with the boundary layer within the diffuser shroud, the aerodynamic noise is reduced substantially.

4)Improved safety: The wind turbine, rotating at a high speed, is shrouded by a structure and is also safe against damage from broken blades.

4. Development of a Shrouded Wind Turbine with Compact Brimmed Diffuser

For the application to a mid-size wind turbine, we have been developing a compact-type brimmed diffuser. For the 500W wind-lens turbine, the length of brimmed diffuser Lt is 1.47D and still relatively long as a collection-acceleration structure for wind. If we apply this brimmed diffuser to a larger wind turbine in size, the wind load to this structure and the weight of this structure becomes severe problems. Therefore, to overcome the above-mentioned problems, we propose a very compact collection-acceleration structure (compact brimmed diffuser), the length Lt of which is quite short compared to D, i.e., $Lt < 0.4D$. We made a couple of compact brimmed diffusers in a range of a relatively short one to a very short one of $Lt = 0.1– 0.4D$. We conducted the output performance test of those wind-lens turbines with compact brimmed diffuser in a wind tunnel experiment and also carried out a field test using a prototype 1kW type model.

Fig.4 500W wind-lens turbine (rotor diameter 0.7m)

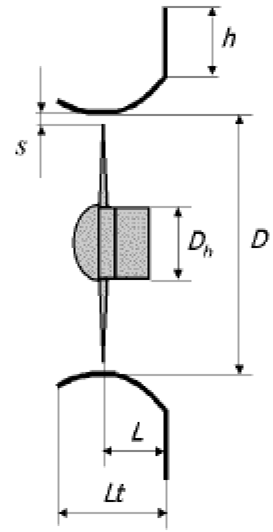

Fig .5 Schematic of wind-lens turbine

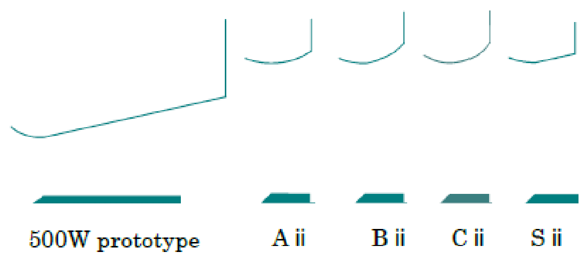

Fig.6 Wind Lens Shapes

4.1. Experimental method in output performance test of compact wind-lens turbines

A large wind tunnel with a measurement section of 15m long, 3.6m wide, 2m high was used. To avoid a blockage effect, removing the ceiling and both side walls, we used it with an open-type test section. For the size of the brimmed diffuser in the present experiment, the throat diameter D is 1020mm and the rotor diameter is 1000mm. Fig.6 shows a schematic of a compact wind-lens turbine. We made four types of diffusers called A, B, C and S-type with different sectional shapes, as shown in Fig.6. Table 1 shows the length ratios L_t /D and the area ratios of (exit area)/(throat area) for each diffuser model. All diffuser types of A to S show the almost same L_t /D, but show the different area ratio μ. For S-type, it has a straight sectional shape as like the 500W prototype. Other three types of A to C have the curved sectional shapes, as shown in Fig.6. For C-type, we adopted the cycloid curve for the sectional shape. Here, the hub ratio D_h/D is 13% and the tip clearance s is 10mm.

Diffuser	Prototype	A ii	B ii	C ii	S ii
Lt/D	1.470	0.225	0.221	0.221	0.225
μ	2.345	1.173	1.288	1.294	1.119

Table1 Parameters of wind-lens shapes

As for the experimental method, connecting torque transducer (the rating 10Nm) to the wind turbine and in the rear of it, an AC torque motor brake was set for the loading. We measured the torque Q (N m) and the rotational speed n (Hz) of the wind turbine in the condition that the turbine loading was gradually applied from zero. The calculated power output P (W) = $Q.2\pi n$ is shown as a performance curve. The shrouded wind turbine model with a compact brimmed diffuser was supported by a long straight bar from the measurement bed which was placed in the downstream and consists of a torque transducer, a revolution sensor and an AC torque motor brake, as shown in Fig.7. The approaching wind speed U_o was 8m/s.

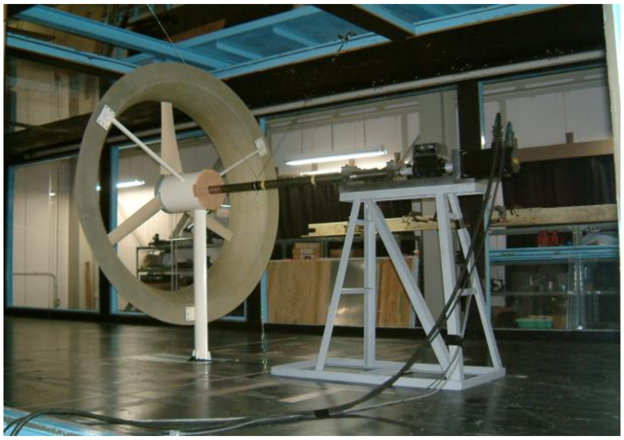

Fig. 7 Output performance test of wind-lens turbine

4.2. Selection of compact brimmed diffuser shape as wind lens

Fig. 8 shows the experimental result of the shrouded wind turbines with compact brimmed diffuser of Aii, Bii, Cii and Sii type. The height of brim is 10%, i.e., h=0.1D. The horizontal axis shows the blade tip speed ratio $\lambda=\omega r/U_o$, here ω is the angular frequency, 2πn, and r is the radius of a wind turbine rotor (r=0.58m). The vertical axis shows the power coefficient C_w (=$P/(0.5\rho U_\infty{}^3 A)$, A is the rotor swept area, πr^2). The wind turbine blade with MEL wing section contour was designed using a three-bladed wind turbine resulting in an optimum tip speed ratio of 5.0. As shown in Fig. 7, when a compact brimmed diffuser is applied, we have successfully achieved a remarkable increase in the output power coefficient approximately 1.9– 2.4 times as large as a bare wind turbine. Namely, the C_w is 0.37 for a bare wind turbine, on the other hand, the C_w is 0.7 – 0.88 for a wind turbine with a compact brimmed diffuser.

Fig 8 also shows the variation of $C_{w,\max}$ with the diffuser length L_t /D, here $C_{w,\max}$ is the maximun value of C_w in the output performance curves as is shown in Fig.8. As it is expected, the $C_{w,max}$ value becomes smaller, as the diffuser length L_t /D becomes smaller. However, when the brim height is larger than 10%, i.e., in case of h>0.1D, the C_w of a wind-lens turbine with C0-type diffuser shows almost twofold increase compared to a bare wind turbine and the one with Ciii-type diffuser shows 2.6 times increase. Thus, we can expect 2-3 times increase in output performance, even if we use a very compact brimmed diffuser as the wind-lens structure.

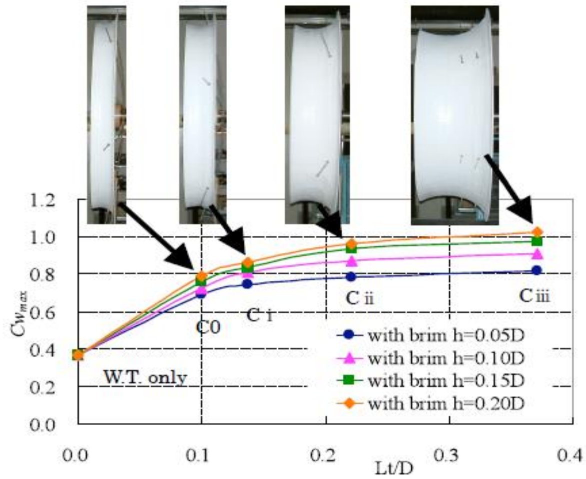

Fig. 8 Maximum power coefficient Cw,max vs. C-type wind-lens length

4.3. Field Experiment

As described before, one of the merits of wind-lens turbine is the brim-based yaw control. Namely, owing to the brim, the wind-lens turbine automatically turns to face the wind. However, for the compact wind-lens structure, it is difficult to realize the wind-lens turbine as the upwind-type wind turbine. Therefore, we made a prototype compact wind-lens turbine as a downwind-type one.

4.3.1. 1kW Wind-lens Turbine

For 1kW downwind-type wind turbine, we selected the Cii-type diffuser (Lt /D=0.22) as the wind-lens structure.

Diffuser	C iii	C ii	C i	C0
Lt/D	0.371	0.221	0.137	0.100
μ	1.555	1.294	1.193	1.138

The brim height is 15%, i.e., h=0.15D. Here, D is 1400mm and the rotor diameter is 1380mm. Fig.9 shows the prototype 1kW wind-lens turbine. We conducted a field experiment using this 1Kw wind turbine. Fig.10 shows the result of performance test on a windy day. The field data are plotted as 10 minutes average data. The power curve is plotted along the C_w =1.0 curve and the high output performance of the present wind-lens turbine is demonstrated. We obtained threefold increase in output power as compared to conventional (bare) wind turbines due to concentration of the wind energy.

Fig. 9 1kW wind-lens turbine (rotor dia 1.38m), downwind type

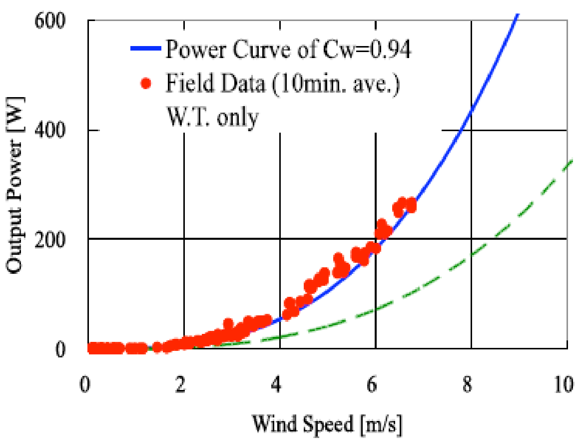

Fig 10 Field experiment of 1kW wind-lens turbine

5. CONCLUSION

A collection-acceleration devise for wind, "the brimmed diffuser", which shrouds a wind turbine, is developed. Significant increase in the output power of a micro-scale wind turbine is obtained. With a relatively long diffuser (L_t =1.47D), a remarkable increase in the output power of approximately 4-5 times that of a conventional wind turbine is achieved. This is because a low-pressure region due to a strong vortex formation behind the broad brim draws more mass flow to the wind turbine inside the diffuser.

For the purpose of the application to a mid-size wind turbine, we developed a very compact brimmed diffuser (wind-lens structure). Using this compact brimmed diffuser, we achieved two-threefold increase in output power as compared to conventional (bare) wind turbines due to concentration of the wind energy.

Incidentally, if we adopt the swept area A* instead of A (due to the rotor diameter), where A* is the circular area due to the outer diameter of brim at diffuser exit, the output coefficient based on A* becomes 0.48-0.52 for those compact wind-lens turbines. It is still larger than the C_w (=0.37) of conventional wind turbines. It means that the compact wind-lens turbine clearly show higher efficiency compared to conventional wind turbines, even if the rotor diameter of a conventional wind turbine is the same as the brim diameter.

REFERENCES

1) O.Igara, "Research and development for shrouded wind Turbines", Energy conversion and Management 21,1981, pp.13-48.
2) B. L. Gilbert and K. M. Foreman, "Experiments with a diffuser-augmented model wind turbine", *Trans. ASME, J, Energy Resources Technology* **105**, 1983 pp.46-53.
3) Y. Ohya, T. Karasudani, A. Sakurai, M. Inoue,"Development of a high- performance wind turbine equipped with a brimmed diffuser shroud", *Trans. of the Japan Society for Aeronautical and Space Sciences*, **49**-163,2006, pp.18-24
4) K. Abe, M. Nishida, A. Sakurai, Y. Ohya, H.Kihara, E. Wada, K. Sato, "Experimental and numerical investigations of flow fields behind a small-type wind turbine with flanged diffuser", *J. Wind Eng. Ind. Aerodyn*. **93**, 2005, pp.951-970.
5) K. Abe, H. Kihara, A. Sakurai, M. Nishida, Y. Ohya, E. Wada, K. Sato, "An experimental study of tip-vortex structures behind a small wind turbine with a flanged diffuser", *Wind and Structures* 9-5, 2006, pp.413-417.