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# A NEW APPROACH TO IMPROVE THE PERFORMANCE OF AN EXISTING SMALL WIND TURBINE BY USING DIFFUSER

***Md. Mahfuz Sarwar*** [1]***, Nazia Nawshin***[2]***, Muhammad Ali Imam***[1] ***and Mohammad Mashud*** [2]
[1] *Center for Environmental Safety and Risk Engineering (CESARE), Victoria University, Melbourne, Australia*
[2] *Department of Mechanical Engineering, Khulna University of Engineering & Technology (KUET), Khulna, Bangladesh*
*E-mail: mdmahfuz.sarwar@live.vu.edu.au*

## Abstract

*For the last few years a great deal of research work has been done in the field of wind energy to improve the performance of small wind turbines for domestic application. In this paper, a new approach of wind turbine is discussed. A new wind turbine system is developed that consists of a diffuser shroud with a broad-ring brim at the exit periphery and a small wind turbine inside it. Here, the improved effects of diffuser had on the overall performance of a small wind turbine system been studied. Besides, the effect of the diffuser shape had on the wind speed was analyzed by experimental setup and found that the wind speed in the diffuser was greatly influenced by the diffuser open angle, flange height, hub ratio, center body length, and inlet shroud shape and so on. The wind speed is increased near the inlet region of the shrouded diffuser. As a result, the output power co-efficient was increased remarkably by a factor of 2.5 to 3 times than that of a conventional wind turbine usually achieved in the field experiment.*

**Key Words:** Wind turbine, Shroud and Brim, Static pressure co-efficient, Power co-efficient.

## 1. 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 resources is an important subject. Furthermore, as concerns for environmental issues (i.e., global warming, etc.) continue to grow, the development and application of renewable and clean new energy resources 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 Bangladesh is extremely small. As for the reasons, various causes are conceivable. For example, limited local area suitable for wind power plants, the complies terrain compared to that in European or North American countries and turbulent nature of the local wind are pointed out. Therefore, the introduction of new wind power system that produces higher power output even in areas where lower wind speeds and complex wind patterns are expected is strongly desired.

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. Although there have been several studies of collecting wind energy for wind turbines reported so far [1–7], it has not been an attractive research subject conventionally. Unique research that was carried out intensively in the past is the examination of a diffuser-augmented wind turbine (DAWT) by Gilbert *et al.* [2], Gilbert and Foreman [3], Igra [4] and others around 1980. In these studies, there was a focus on concentrating wind energy in a diffuser with a large open angle, a boundary layer controlled with several flow slots was employed to realize a flow that goes along the inside surface of the diffuser. Thus, the method of boundary layer control prevents pressure loss by flow separation and increases the mass flow inside the diffuser. Based on this idea, a group in New Zealand [5,6] developed the Vortec 7 diffuser augmented wind turbine. They used a multi-slotted diffuser to prevent separation within the diffuser. Bet and Grassmann [7] developed a shrouded wind turbine with a wing-profiled ring structure. It was reported that their DAWT showed an increase in power output by the wing system by a factor of 2.0, compared to the bare wind turbine. Although several other ideas have been reported so far, most of them do not appear to be reaching commercialization.

The present study, regarding the development of a wind power system with high output, aims at determining how to collect the wind energy efficiently and what kind of wind turbine can generate energy effectively from the wind. There appears hope for utilizing the wind power in a more efficient way. In the present study, this concept of accelerating the wind was named the "wind-lens" technology. For this purpose, we have developed a diffuser-type structure that is capable of collecting and accelerating the approaching wind. Namely, we have devised a diffuser shroud with a large brim that is able to increase the wind speed from approaching wind substantially by utilizing various flow characteristics, e.g., the generation of low pressure region by vortex formation, flow entrainment by vortices and so on, of the inner or peripheral flows of a diffuser shroud equipped with a brim. Although it adopts a diffuser-shaped structure surrounding a wind turbine like the others [1–7], the feature that distinguishes it from the others is a large brim attached at the exit of diffuser shroud. Furthermore, we placed a wind turbine inside the diffuser shroud equipped with a brim and evaluated the power output generated. As a result, the shrouded wind turbine equipped with a brimmed diffuser demonstrated power augmentation for a given turbine diameter and wind speed by a factor of about 4–5 compared to a standard micro wind turbine. Furthermore, for the practical application to a small- and mid-size wind turbine, we have been developing a compact-type brimmed diffuser. The combination of a diffuser shroud and a brim is largely modified from the one with a long diffuser with a large brim. The compact “wind-lens turbines” showed power augmentation of 2.5 –3 times as compared to a bare wind turbine.

## 2. Basic working principle of wind turbines

Wind turbines produce electricity by using the natural power of the wind to drive a generator. The wind is a clean and sustainable fuel source, it does not create emissions and it will never run out as it is constantly replenished by energy from the sun. In many ways, wind turbines are the natural evolution of traditional windmills, but now typically have three blades, which rotate around a horizontal hub at the top of a steel tower. Most wind turbines start generating electricity at wind speeds of around 3-4 meters per second (m/s), (8 miles per hour); generate maximum ‘rated’ power at around 15 m/s (30mph); and shut down to prevent storm damage at 25 m/s or above (50mph). The wind turbine converts the kinetic energy of the wind into mechanical power. This mechanical power can be used for specific tasks or a generator can convert the mechanical power into electricity. Simply stated, a wind turbine works the opposite of a fan. Instead of using electricity to make wind, like a fan, wind turbines used wind to make electricity. The wind turns the blades which spin a shaft which connects a generator and make electricity. The power available from the wind is a function of the cube of the wind speed. Therefore if the wind blows at twice the speed, its energy content will increase eight-fold. Turbines at a site where the wind speed averages 8 m/s produce around 75-100% more electricity than those where the average wind speed is 6 m/s.

## 3. Advantages of wind energy

One of the greatest advantages of the wind energy is that it is simple. Second wind energy is a renewable. Some other advantages of the wind energy are that it is widely distributed, cheap and also reducing toxic gas emissions. Wind energy is also advantageous over traditional methods of creating energy. Wind energy may soon be the cheapest way to the produce energy on a large scale. The cost of production wind energy has come down by at least 8%. Along with economy, wind energy is also said diminish the greenhouse effect. Also wind energy no generates pollution. Wind energy is also more permanent type of energy. The wind will exit till the time the sun exits which is roughly another four billions year. Theoretically, if all the wind power available to humankind is harnessed, there can be ten times of energy we use, readily available. On the other hand of wind energy that it is available around the globe and therefore there would be no need of dependence for energy for any country. Wind energy may be the answer to the globes equation of energy of the face of the rising petroleum and gas prices.

Furthermore, there is no demission of energy in the world. But we have limited sources of energy. Day by day the sources of energy are decreasing. So we have to give attention to renewable energy. In power generation sector Renewable energy provides 18 percent of total electricity generation worldwide. Renewable power generators are spread across many countries, and wind power alone already provides a significant share of electricity in some areas: for example, 14 percent in the U.S. state of Iowa, 40 percent in the northern German state of

Schleswig-Holstein, and 20 percent in Denmark. Beside this all renewable energy is not efficient. For some of renewable energy the power generation setup is costly. All of this sense wind energy is the best to produce power. If there is sun in the world, there will be wind flow. If we can increase the wind velocity by using any setup for the conventional wind turbine eventually it will maximize the generated power output.

## 4. Basic concept of high performance wind turbine

### *4.1. Significant effects of diffuser shape on wind acceleration*

To perform the experiment a small sub-sonic wind tunnel of the Fluid Dynamics Laboratory, Khulna University of Engineering & Technology (KUET), was used. It has a 36 cm wide × 36 cm high × 100 cm long measurement section and the maximum wind velocity is 25 m/sec. Two types of hollow-structure models, a nozzle and a diffuser type, were tested (Figure 1). 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.

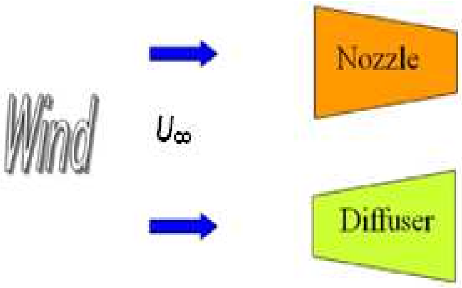

Figure 1. Two types of hollow structures

In the case of using a hollow-structure model, paying attention to the blockage effect in the wind tunnel, the ceiling and both side walls of the measurement section was removed. Namely, we used our wind tunnel with an open-type test section to avoid the blockage effect. The smoke-wire technique was employed for the flow visualization experiment. The experiments revealed that a diffuser-shaped structure can accelerate the wind at the entrance of the body, as shown in Figure 2 [8–10]. The reason is clarified through the flow visualization, as shown in Figure 3. Figure 3a,b shows the flows inside and outside the nozzle- type and diffuser-type models. The flow is from left to right. As seen in the Figure 3(a), the wind tends to avoid the nozzle-type model, while the wind flows into the diffuser-type model as it is inhaled, as seen in Figure 3(b). A twisted Nichrome wire was employed to perform the airflow visualize around the object. Safex was used as smoking fluid. Clear and uniform flow was generated by using Nichrome wire (two coiled) at voltage V=12v.

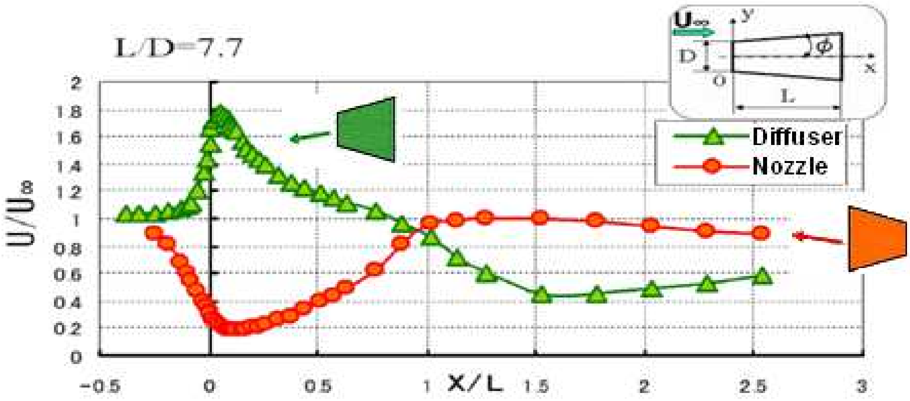

Figure 2. Wind velocity distribution on the central axis of a hollow structure, *L/D* = 7.7. The area ratios $\mu$ (outlet area/inlet area) of the hollow-structure models are 1/4 and 4 for the nozzle- and diffuser-type models, respectively.

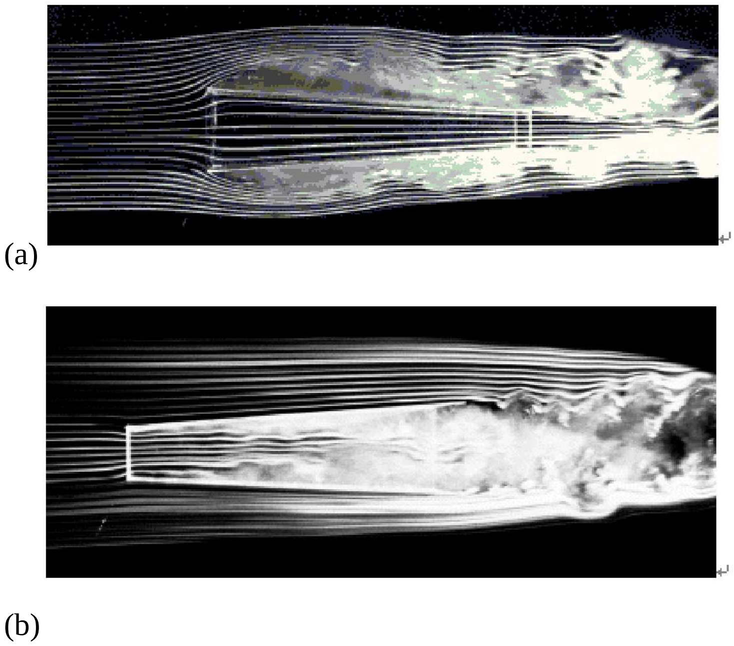

Figure 3. Flows around nozzle- and diffuser-type models. The smoke flows from left to right. (a) Nozzle-type model, (b) Diffuser-type model.

### *4.2. Design Concepts of 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, as shown in Figure 4. Accordingly, the wind flows into a low-pressure region; the wind velocity is accelerated further near the entrance of the diffuser. Figure 5 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 an appropriate structure for entrance was added, 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 [8–10].

Figure 4. Flow around a circular-diffuser model with a brim. The smoke flows from left to right. *L/D* = 1.5. The area ratio $\mu$ (outlet area/inlet area) of the circular-diffuser model is 1.44. Karman vortices are formed behind brim.

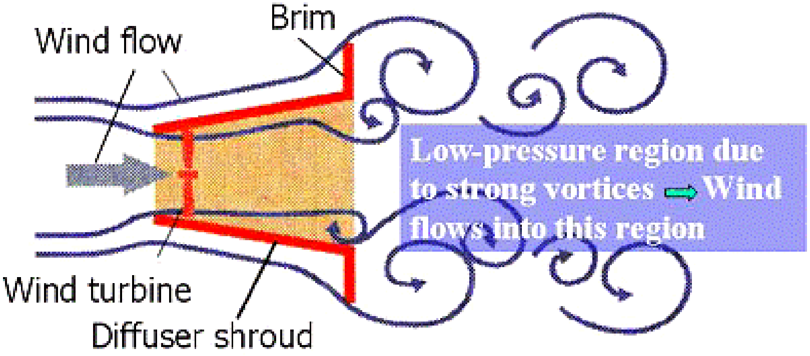

Figure 5. Flow around a wind turbine with brimmed diffuser (wind-lens).

As for other parameters, the diffuser opening angle, the hub ratio, and the center-body length was examined [10-12]. Then the optimal shape of a brimmed diffuser was found [10]. In addition, we are now examining the turbine blade shape in order to acquire higher output power. When a brimmed diffuser is applied, a remarkable increase in the output power coefficient ($C_w = P/0.5\rho A U^3$, P: output power, A: swept area of turbine blades) of approximately 2.5–3 times that of a conventional wind turbine is achieved in field experiment. A simple theory for the present wind-lens turbine was given by Inoue et al [13]. The output performance is decided by the two factors of the pressure discovery coefficient of the diffuser shroud and the base pressure behind it.

## 5. Experimental method

To perform the experiment a small suction type subsonic wind tunnel of the Fluid Dynamics Laboratory, Khulna University of Engineering & Technology (KUET), Khulna, Bangladesh was used. It has a 36 cm wide × 36 cm high × 100 cm long measurement section and the maximum wind velocity is 25 m/sec. various hollow-structure models of the cone type were made by acrylic sheet. The models were placed supported by hock-stand in the center of the wind tunnel test section. The distributions of wind velocity U and the static pressure p along the central axis or periphery of the hollow-structure model were measured with digital pressure gauge. The static pressure coefficient is defined as $C_p = (p - p_\infty)/(0.5\rho U_\infty{}^2)$; where $U_\infty$ is the approaching wind speed, $\rho$ is the air density, and $p_\infty$ is the static pressure that corresponds to $U_\infty$ in a far stream position. The experimental arrangement is shown in figure 6. The representative scale length of a model is the entrance width (entrance diameter) D of 10 cm, the wind velocity is $U_\infty$= 7 m/sec to 10 m/sec

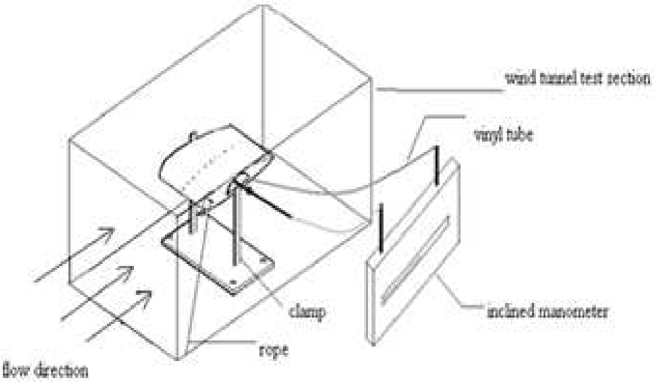

Figure 6. Wind-tunnel test section.

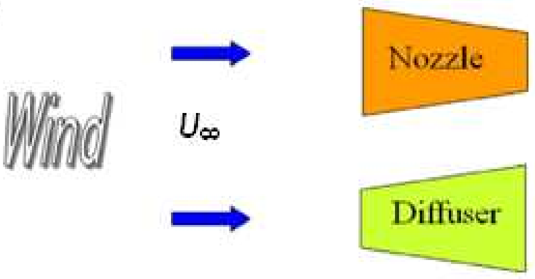

Figure 7. Hollow structure model.

and the Reynolds number is $Re=4\times10^4-1.3\times10^5$. In the case of using a big hollow-structure model, paying attention to the blockage effect in the wind tunnel, we removed the walls of the ceiling and both sides of the test section. Namely, we used a wind tunnel with an open type test section to avoid blockage effect. The smoke (Sefax as smoking fluid) wire (Nichrome) technique was employed for the flow visualization experiment.

### *5.1 Selection of diffuser type*

We examined the inner flow of two typical hollow structures, as shown in figure 3; namely a nozzle-type model that reduces the inside cross section and a diffuser type model that expand the inside cross section downstream. For the nozzle and diffuser types' model, the angle of inclination φ is $3.5^0$. The length ratio L/D is 7.0; here, L is the model length.Figure 2 shows the wind velocity distribution $U/U_\infty$ and static pressure distribution Cp on the central axis of a hollow structure model. As shown in figure 2, the diffuser model has a remarkable effect on the collection and acceleration of the approaching wind. A maximum of $U/U_\infty=1.7$ is shown in the neighborhood immediately after the entrance. Here, x/L=0 is the model entrance and x/L=1 is the model exit. Figure 4 shows the flows inside and outside of the nozzle and diffuser type models. The flow is from left to right. As seen in the figure 3, the wind tends to avoid the nozzle type model, while the wind flows into the diffuser type model as it is inhaled. Examining the optimal angle φ (the half open angle) of this diffuser, it is found that the angle φ of around $3.5^0$ is most effective. Also for the diffusers model, the length ratio of L/D was examined. Wind speed gradually increases with L/D, as shown in the figure 2. Thus, it was confirmed that the diffuser structure is most effective for collecting and accelerating the wind.

### *5.2 The effect of shrouded diffuser*

It was found that a remarkable increase in wind speed was obtained if a long diffuser body over L/D=3 is used. However in the case of commercialization it is preferable to have a short diffuser body with a L/D of less than 2 that has similar performance to that of a long diffuser body. Therefore, we examined a short diffuser-type structure which is capable of providing more effective performance by applying various ideas to the short body. As a result of several attempts, it was found that wind speed is increased by adding an appropriate entrance (called an inlet shroud) and a ring type flange at the exit periphery to the diffuser body. The inlet shroud opening has a smooth curved surface surrounding the entrance of the diffuser model. The brim is a ring type plate with a height of h=3 cm (h/D= 0.30), and is attached vertically to the outer periphery of the diffuser model at the exit. As shown in figure 8 and in figure 9, when both the inlet shroud and a range of variation in brim heights (h/D= 0.1, 0.2, 0.3) are employed, a remarkable increase in wind speed can be obtained against the no brim (h/D= 0) condition, exceeding the case of a diffuser model only, and achieving a high velocity that is 1.6 to 2.5 times greater than that of the approaching winds velocity $U_\infty$.

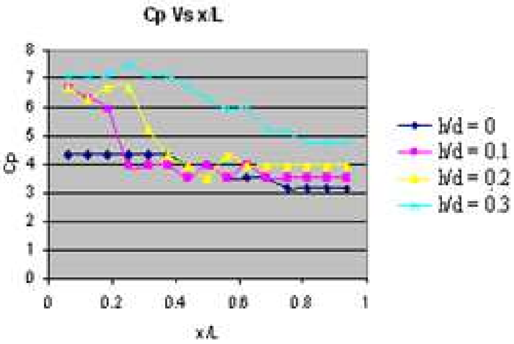

Figure 8. Pressure along the flow direction

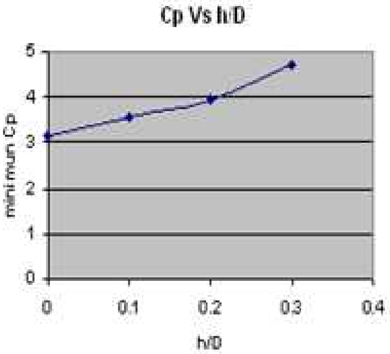

Figure 9. Relation between pressure and brim height

The effect of the inlet shroud is found in the following point: It restrains flow separation at the entrance fairly well and the wind flows in more smoothly. Further examination of the inlet shroud was not conducted in the present experiment.

### *5.3 Optimization of wind velocity acceleration*

Here, the reason of increased wind speed near the entrance was discussed when a brim is attached to the outer periphery of a diffuser exit. Figures 4 show the visualization results of both of the flows around a circular diffuser without a brim and one equipped with a brim using the smoke wire technique. The brim used for the circular diffuser is a ring type circular disk with a height of h=3 cm (h/D=0.30) and is attached to the outer periphery of the diffuser exit. In figure 3(b) clear vortex formation is not observed in downstream of the diffuser without brim, while vortex formation like the karmon vortex street is clearly observed in downstream of the brim (figure 4). As is observed in figure 8, owing to the vortex formation, the static base pressure $p_b$ in the exit area at around x/L=1 of the diffuser equipped with a brim falls to a fairly low pressure compared to that of the upstream flow $p_\infty$, in comparison to the case of diffuser without a brim. The base pressure coefficient at the exit of x/L=1 is defined as $C_{pb} = (p_b - p_\infty)/(0.5\rho U_\infty^2)$. For the diffuser without a brim $C_{pb}$=-0.2. In contrast, for the diffuser equipped with a brim of h/D=0.3, $C_{pb}$=-0.75. As a result, wind velocity at the inlet end is further accelerated for this additional suction pressure. The optimum size of the brim was examined to obtain the largest increase in wind speed near the diffuser entrance. The model used was a circular diffuser with L/D=1.5. Circular brims with various heights of h were attached to the diffuser exit. Figure 8 shows the pressure variation along the central axis for different brim height. It is found that a brim of around h/D=.30 is the most effective for wind acceleration. A brim larger h/D=0.30 causes a pressure increase in the upstream flow in front of the diffuser and prevents the approaching wind to smoothly flowing in.

## 6. Wind power generation performance test

As for the experiment method, a torque transducer was connected to the wind turbine and an DC torque motor brake was set behind it for the loading. We measured the torque Q and rotational speed n of the wind turbine under the condition of gradually increasing turbine load from zero. Figure 10 shows the experimental results. The horizontal axis shows the blade-tip speed ratio $\lambda = \omega r / U_\infty$. Here, $\omega$ is the angular frequency, 2πn, and r is the radius of the wind turbine rotor. The vertical axis shows the power coefficient $C_w (= P/(0.5\rho U_\infty^3 A)$ [14-15]; where, A is the rotational area of the wind turbine rotor. A wind turbine blade with a NACA63-2 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. 10 when a brimmed diffuser is applied, a remarkable increase in the output power coefficient of approximately five times that of a conventional wind turbine is achieved.

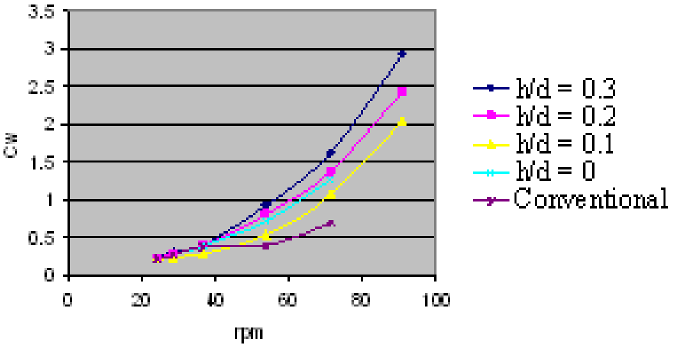

Figure 10. Power output comparisons

## 7. Important features of a wind turbine with brimmed diffuser shroud

The important features of the wind turbine equipped with a brimmed diffuser shroud are as follows:

- (i) Fivefold increases in output power as compared to conventional wind turbines due to concentration of the wind energy.
- (ii) Brimmed-base 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.
- (iii) Significant reduction in wind turbine noise: Basically, am aerofoil section of the turbine blade which gives the best performance in a low-tip speed ratio range is chosen. Since the vortices generated from blade tips are considerably suppressed through the interface with the boundary layer within the diffuser shroud, the aerodynamic noise is reduced substantially [14].
- (iv) Improved safety: The wind turbine, rotating at a high speed, is shrouded by a structure and is also safe against dame from broken blades.

## 8. Conclusions

A new wind turbine system was developed that can generate power output under the condition of low wind speed and obtain a remarkably higher power output compared to conventional systems. Wind collection-acceleration device was examined that makes it possible to concentrate the wind energy. It was confirmed that a hollow structure diffuser is as effective as the shroud form for collecting and accelerating the wind. Significant increase in the output power of a micro-scale wind turbine was obtained.

To obtain a further increase in wind speed inside the diffuser shroud, a brim of proper height is attached to the outer periphery of the diffuser exit, successfully realizing a remarkable increase in wind speed of 2.5 to 3.0 times that of approaching wind speed. This is because of the brim generates a very-low-pressure region in the exit area of the diffuser by forming strong vortices and drawing the wind into the diffuser. It means that the compact wind-lens turbines clearly show higher efficiency compared to conventional wind turbines, even if the rotor diameter of a conventional wind turbine is extended to the brim diameter.

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