Applied Mechanics and Materials *Online: 2014-01-08*
ISSN: 1662-7482, Vol. 493, pp 294-299
doi:10.4028/www.scientific.net/AMM.493.294

High-Efficiency Shrouded Micro Wind Turbine for Urban-Built Environment

Buyung Kosasih[1,a] and S.A. Jafari[2,b]

[1,2]School of Mechanical, Materials and Mechatronics Engineering,

University of Wollongong,

NSW 2500 Australia

[a]buyung@uow.edu.au, [b]sahj551@uowmail.edu.au,

Keywords: computational fluid dynamic, coefficient of performance, diffuser, micro wind turbine, shroud

Abstract. Shrouding (*diffuser augmented*) horizontal axis micro-wind turbine has been shown to be an effective ways to potentially increase the power output of micro wind turbine for applications in built environments. It is well understood that the degree of the performance enhancement depends on several factors including the diffuser shape and geometries, blade airfoils, and the wind condition at the turbine site. The effect of diffuser shape and geometries is reported in this paper. Computational fluid dynamic (CFD) simulations of a small wind turbine with a simple frustum diffuser shrouding have been carried out. The diffuser has been modeled with different shapes with the aim to understand the effect of length and area ratio on power augmentation phenomenon. The simulations provide some parameterized figures which present method to determine the beneficial range of frustum diffuser geometries for diffuser shrouded horizontal axis wind turbines.

Introduction

Power generation from wind in urban built-environment is one of the emerging research areas in the renewable energy field. The idea is underpinned by the benefits from having power generated at the point of use. Despite of these benefits, there are technological, economical and social hurdles to be overcome before urban power generations from wind become reality. Urban wind turbine installations are undermined by relatively low power output and unreliable performance due to unfavourable urban wind conditions such as low wind energy content (*low wind velocity*), continuously variable wind directions, high turbulence level and strong gust occurrences.

Diffuser-augmented wind turbine has been shown by many studies [1-4] can significantly increase power output. Simple diffuser consists of three sections: inlet section, turbine section or throat, and diffusing outlet section. The overall performance augmentation depends on the design of each section and governed by the efficiencies of the inlet and outlet sections, the static pressure at the outlet area of the diffuser, and the resistance from the turbine [5]. For simple design as shown in Fig. 3, parameters that influence the performance include length, L and expansion angle, α of the diffuser. Despite of the importance of diffuser geometrical parameters there is limited experimental study comparing the performance of the bare turbine with shrouded turbine under controlled flow condition and rotor speed.

Matsushima *et al.* [6] studied the effect of diffuser length, L, expansion angle, α and brim height on the increase of wind speed under unloaded condition (*no turbine*) at the throat. L/D from around 0.4 to 3 was investigated. van Bussel [4] using simple momentum theory reached the same finding *i.e.* proportional increase of coefficient of performance, C_p with diffuser area ratio. On the other hand increasing α initially increases wind speed ratio but after reaching the maximum, the ratio decreases indicating the occurrence of detached flow inside the diffuser.

Ohya *et al.* [7] showed that with the addition of broad ring flange (*brim*) in the outlet of the diffuser the pressure at the exit plane can be lowered further due to the vortex formation at the outlet plane.

Hence performance of brimmed diffuser shrouded turbine is greater compared to diffuser only. Compared to same diffuser without brim, the flow must expand to lower pressure. As the expansion in the brimmed diffuser and non-brimmed one is the same, the pressure downstream of the brimmed diffuser turbine must be lower and hence flow is accelerated [8].

Another mechanism was also identified by Abe *et al.* [9] who observed the affected flow structure behind the turbine particularly near the blade tip. The presence of the diffuser wall suppress the separation region hence increase the power output of the turbine. This is more evident at low tip speed.

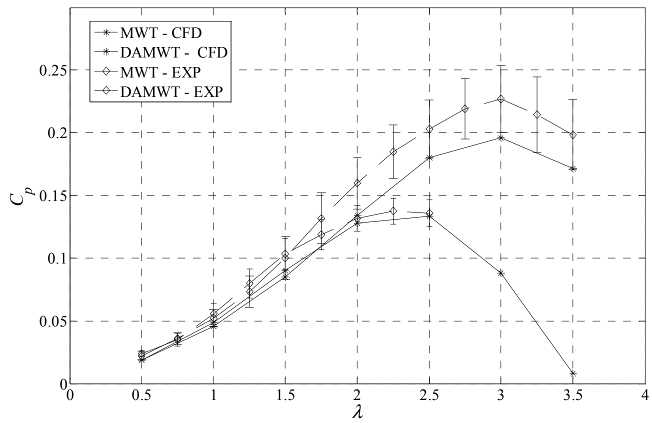
To find the influence of shroud geometrical features, Shives and Crawford [10] using CFD investigated the effect of diffuser with aerofoil (NACA 0015) cross section geometrical features. It was found that inlet efficiency (i) has only small impact on the power output. And flow separation in the diffuser leads to significant lowering of the pressure recovery coefficient (ii) which in turn reduces the overall power coefficient, *Cp*. And base pressure coefficient (iii) is the most influential parameter in *Cp*.

The research presented in this paper parameterizes the power augmentation of a small wind turbine (AMPAIR 300) shrouded with a simple frustum diffuser, based on diffuser's length and area ratio (outlet area/inlet area) using CFD simulations. The results of bare turbine simulations were compared with experimental data from the wind turbine's manufacturer. The general diffuser shape selected for this turbine is a simple frustum, because of its low complexity and cost for manufacturers.

Experimental investigation of a shrouded micro wind turbine model

A micro wind turbine model has been made in laboratory. Figure 1(a) shows the turbine with diffuser. The model turbine has three blades. The blades have NACA 63-210 airfoil profile. The rotor diameter is 190 mm. The tip gap is kept as small as practically possible *i.e.* 2-3 mm. The diffuser length is 120 mm resulting in *L/D* of 0.63. The expansion angle, α of the diffuser is 12^{o} resulting in diffuser outlet and inlet area ratio of 1.61. The turbine was placed in a wind tunnel with working section of 450 mm x 450 mm x 1500 mm and wind speed up to 25 ms^{-1}.

(a)



(b)

Fig. 1 (a) Wind tunnel test section showing the model shrouded micro wind turbine. (b) Comparison of C_p of MWT and DAMWT against λ.

A comparison between C_p of the micro wind turbine (MWT) and the diffuser augmented micro wind turbine (DAMWT) is shown in Figure 1(b) to assess the effect of diffuser on the power output. As can be seen the maximum C_p of the MWT obtained by CFD simulation is 13.8% achieved in λ = 2.3 while in the DAMWT it is 19.5% and in λ = 3, which means the performance has 41.3% increased. This indicates that at low λ, MWT and DAMWT C_p curves agree well, but at higher λ power extraction increases by increasing λ until an optimum point, at which further increase in λ reduces C_p.

Analysis of a commercially available micro wind turbine

Computational fluid dynamic model validation. The small wind turbine selected for simulation was AMPAIR 300 Watt micro wind turbine. This model has three blades and a quasi-conical hub. Figure 2 show the actual turbine on the left and its virtual bare model on the right. The rotor radius is 650 mm (D = 1300 mm). Figure 3 shows the virtual turbine shrouded with a diffuser. The diffuser length is shown by *L* and the difference between inlet and outlet radius of the diffuser is shown by H. The turbine was modeled in a virtual wind tunnel with diameter of 4 m and length of 10 m which can be seen in Figure 4.

Fig. 2 AMPAIR 300 on the left and CFD model of AMPAIR 300 on the right.

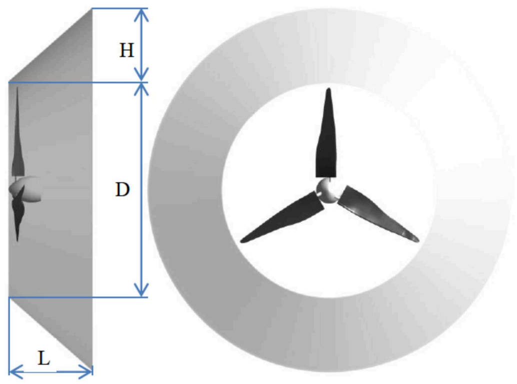


Fig. 3 Dimensional parameter of diffuser.

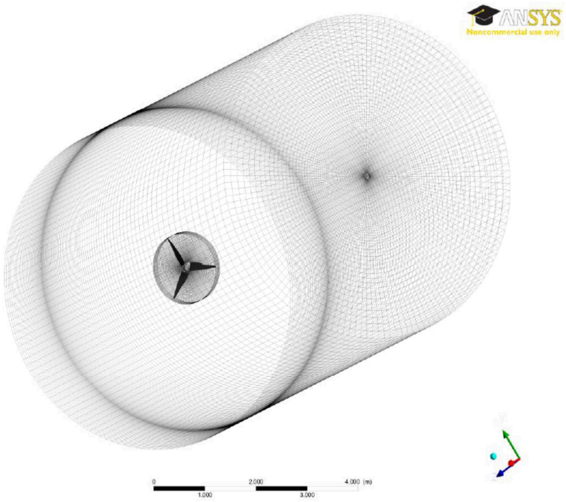


Fig. 4 Mesh of the computational domain.

The results were validated by power output reported from the manufacturer in different wind speeds. Bare turbine simulations have been done in wind speeds of 5, 7.5, 10, 12.5 and 15m.s^{-1}. Power and RPM data for different wind speeds are given by the manufacturer. The RPM of the turbine in each wind speeds has been read from the curve provided by the manufacturer. Then simulations were done with these RPM and wind speeds. Power outputs obtained by these simulations are compared with power output reported by the manufacturer and is shown in Figure 5.The results are not exactly the same and there is difference between simulation and experimental results. But this difference is acceptable because all the boundary conditions in the simulations could not be set as in the manufacturer's experimental tests.

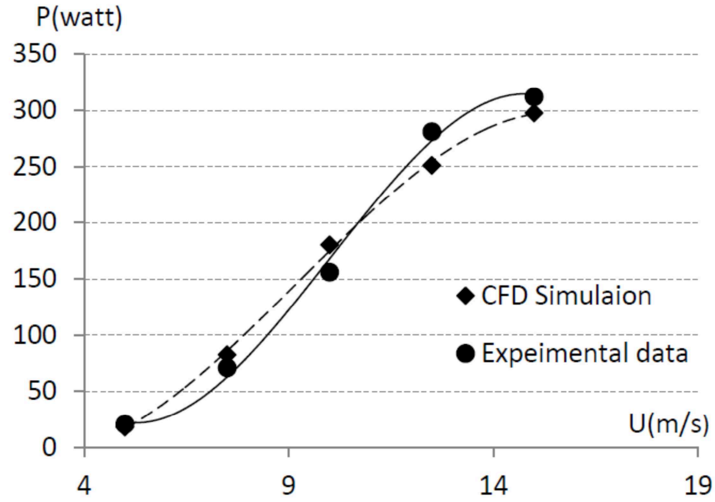


Fig. 5 Comparison of the power output of the AMPAIR 300 provided by the manufacturer and the simulation results.

Parametric study. *Effect of L/D on power output.* Power extracted from a wind turbine can be expressed in different λ (tip-speed-ratio), based on rotor's operation. Higher wind energy can be extracted in higher λs. But there is an optimum point at which further increases in λ reduces output power. A turbine should operate at this λ, however it does not practically happen, and power output is less than its maximum. Figure 6 shows power output of bare AMPAIR 300 wind turbine and shrouded AMPAIR 300 turbine with a diffuser with constant *L/D* and different *H/D* ratios versus λ.

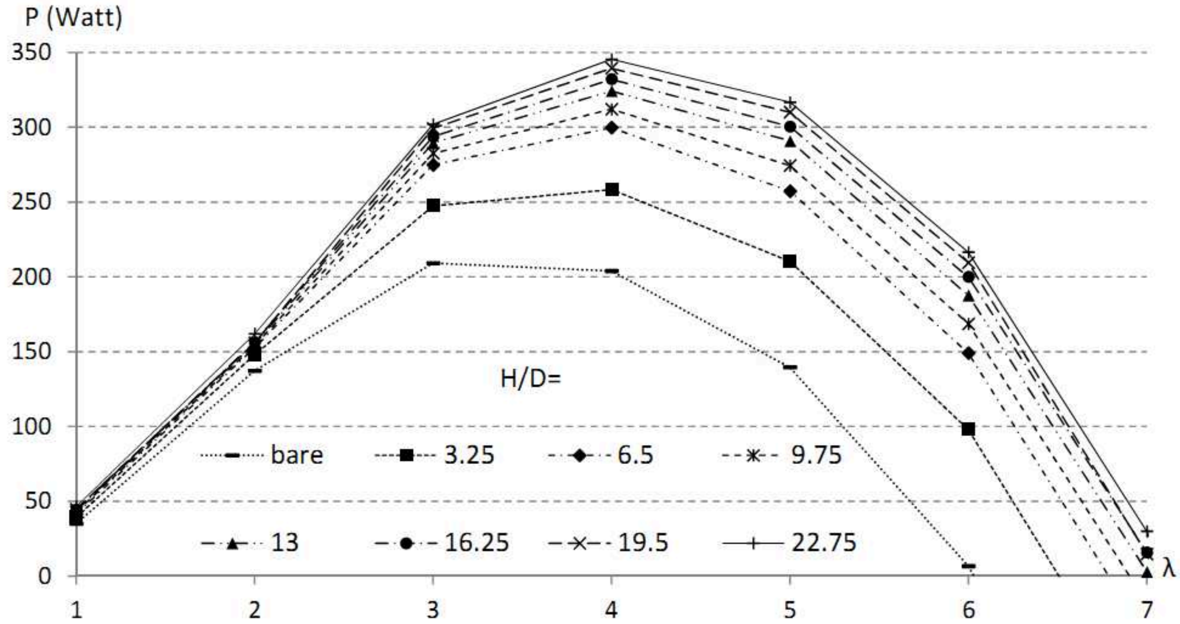


Fig. 6 Power output of AMPAIR 300 CFD shrouded by diffuser with L/D = 0.1 versus λ at U = 10 ms^{-1}

Effect of H/D. In Figure 7, each point shows power output of the DAMWTs at optimum λs taken from Figure 6. Hence, all these values should be compared with maximum power output of the bare turbine which was *210 W*. This figure presents parameterized power extraction of the diffuser augmented small wind turbine in terms of *L/D* and *H/D*.

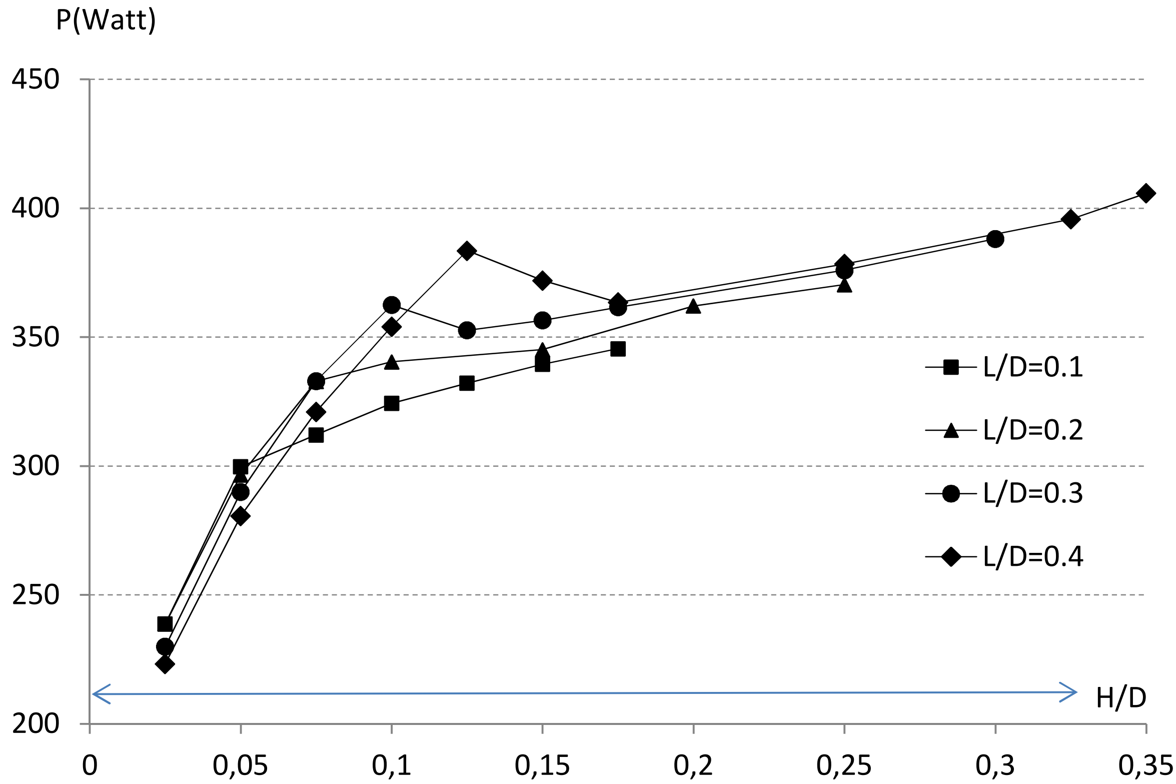


Fig. 7 Maximum power output of the DAWT model shrouded by diffuser with different L/D and H/D (maximum power output of the bare CFD model= 210 Watt).

As can be seen in Figure 7, power extraction of the turbine is significantly affected by area ratio (*H/D*). As the *H/D* is higher, more power is extracted. It can also be seen that greater power augmentation is possible when the *L/D* is higher, while power augmentation in lower *H/D* is smaller for diffusers with a higher *L/D*. This is because changing *L/D* affects both flow separation from the diffuser surface and viscous losses created in the diffuser.

Estimating the beneficial range of diffuser geometric parameters. Shrouding a turbine with a diffuser generally enhances its power out. But this approach may be beneficial only when the power generated by DAMWT is greater than a larger bare turbine with a swept area equal to the outlet of the diffuser. Hence an efficient method to evaluate performance of the diffusers is parameterizing the C_p (coefficient of performance) of the DAMWTs by the *H/D* and *L/D* factors. Figure 8 shows C_p of the DAMWTs which their power outputs are shown in figure 7. In this figure all the values should be compared with maximum C_p of the bare turbine which is *0.257*.

In Figure 8 the solid line which has C_p value of *0.257* is the threshold of beneficial diffuser designs. When C_p is higher than 0.257, the diffuser design is better. Figure 7 shows increasing *H/D* enhances the power augmentation of DAMWT, however Figure 8 shows this option is not beneficial beyond certain *H/D,* which in this turbine is between H/D of 0.125 – 0.16. Figure 8 also shows increasing *L/D*, lowers the maximum C_p which can be achieved in the DAMWT although greater power augmentation can be achieved in higher *L/D* (as can be seen in Figure 7). Hence there is a maximum *L/D* for the diffuser beyond which the benefit of DAMWT cannot be achieved.

Conclusion

AMPAIR 300 wind turbine shrouded with different frustum diffuser shapes has been studied using CFD simulations. The effect of length and area ratio of the diffuser on augmentation performance of the created DAWTs have been elucidated. It was shown that although increasing area ratio enhances the power augmentation, this modification is not beneficial for the DAMWT further than a specific point. It was also shown that increasing the length of the diffuser lowers the maximum C_p that can be achieved in the DAMWT, although a greater power augmentation can be achieved with longer diffuser. And there is a limited H/D range in which the benefit of DAMWT can be justified. The results of this study demonstrate how a commercial/existing micro wind turbine can have increased performance by using an appropriately designed frustum diffuser.

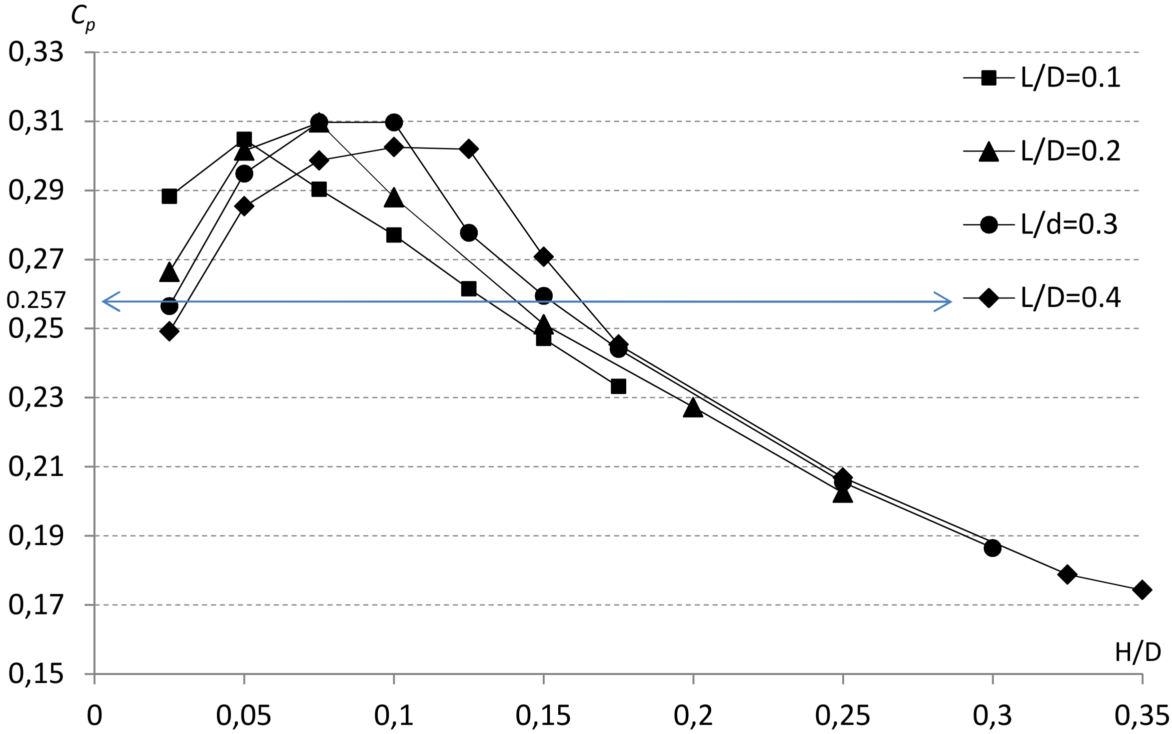


Fig. 8 Maximum C_p of the DAWT model shrouded by diffuser with different L/D and H/D (maximum C_p of the bare CFD model= 0.257).

References

[1] K.M. Foreman, B. Gilbert, R.A. Oman, Diffuser Augmentation of Wind Turbines, Solar Energy, 20 (1978) 305-311.
[2] O. Igra, Research and Development for Shrouded Wind Turbines, Energy Conv. & Mgmt., 21 (1981) 13-48.
[3] M.O.L. Hansen, N.N. Sorensen, R.G.J. Flay, Effect of Placing a Diffuser around a Wind Turbine, Wind Energy, 3 (2000) 207-213.
[4] G.J.W. van Bussel, The Science of Making More Torque from Wind: Diffuser Experiments and Theory Revisited, Journal of Physics: Conference Series, 75 (2007) 1–12.
[5] C.J. Lawn, Optimization of the Power Output from Ducted Turbines, Proc. Instn. Mech. Engrs. Part. A: J. Power and Energy, 217 (2003) 107-117.
[6] T. Matsushima, S. Takagi, S. Murayama, Characteristics of a Highly Efficient Propeller Type Small Wind Turbine with a Diffuser, Renewable Energy, 31 (2006) 1343-1354.
[7] Y. Ohya, T. Karasudani, A. Sakurai, K. Abe, M. Inoue, Development of a Shrouded Wind Turbine with a Flanged Diffuser, J. Wind Eng. and Industrial Aero., (2008) 524-539.
[8] K. Abe, Y Ohya, An Investigation of Flow Fields around Flanged Diffusers Using CFD, J. Wind Eng. and Industrial Aero., 92 (2004) 315–330.
[9] K. Abe, M. Nishida, A. Sakurai, Y. Ohya, H. Kihara, E. Wada, K. Sato, Experimental and Numerical Investigations of Flow Fields behind a Small Wind Turbine with a Flanged Diffuser, J. Wind Eng. and Industrial Aero., 93 (2005) 951 – 970.
[10] Shives M, Crawford C (2010). Computational Analysis of Ducted Turbine Performance. 3rd Int. Conf. on Ocean Energy, 6 Oct. 2010, Bilbao.