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Wind tunnel test of a ducted horizontal axis wind turbine.

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SUMMARY:

Wind energy technology for smaller scales has not been consolidated, different models can be considered depending on local urban environment, designs are currently developed to fit different applications. Wind turbine design in urban location need to consider architecture design of building, characterizations of energy production of ducted wind turbine is of particular interest for urban wind energy application. HAWT works at highers axis speed velocity, also they demand an orientation system and the blades are prone to damage in high turbulence conditions, security operation is a relevant point for wind turbine design in urban environment, particularly considering the case of a blade damage. Ducted horizontal axis wind turbine (DHAWT) can be useful for wind energy urban application considering higher levels of safety in the case of a blade damage. In our work we present results achieved during measurements in a test bench developed in a wind tunnel testing facility. Non dimensional power curve of a simple ducted horizontal axis wind turbine (DHAWT) with convergent duct and diffuser is presented.

Keywords: ducted wind turbines, urban wind energy, wind tunnel model test

1. INTRODUCTION

Urban wind energy consists of the utilization of wind energy technology to the urban and suburban built environment Stathopoulos et al., 2018. Wind energy technology for smaller scales has not been consolidated, different models can be considered depending on local urban environment, designs are currently developed to fit different applications. Poor performance of wind turbines in the analyzed engineering structures can be attributed to an inadequately performed wind resource assessment and an unsuitable selection of wind turbine types, thus indicating strong potential for future work in this regard Škvorc and Kozmar, 2021 . Considering wind turbines in buildings, Sharpe and Proven, 2010 describes the concept development and work to date, of an innovative true building integrated wind turbine. In KC et al., 2019 it is reviewed the diverse application of small wind turbine technology (SWTs) in the built environment also investigates the extent to which the international design standard IEC 41400-2. This review show that the wind models incorporated in IEC 61400-2 is not suitable for installation of SWTs in the built environment. Thus, SWT design can be made more consistent with urban wind conditions and their performance and reliability can be assured. In terms of wind turbines models, horizontal axis wind turbines (HAWT) have the advantage of highers power coefficient in comparison with vertical axis wind turbines (VAWT). HAWT works at highers axis speed velocity, also they demand an orientation system and the blades are prone to damage in high turbulence conditions, security operation is a relevant point for wind turbine design in urban environment, particularly considering the case of a blade damage. Ducted horizontal axis wind turbine (DHAWT) can be useful for wind energy urban application considering higher levels of safety in the case of a blade damage. Firsts reported works of DHAWT were Igra, 1977; Lilley, 1956; Oman RA, 1973. Recent works have analyzed with actuator disc CFD model the effect of placing a diffuser around a wind turbine, Hansen et al., 2000. The analysis done in Bontempo and Manna, 2016 with a semi-analitical approach has pointed out that the duct thrust plays a key role in the enhancement of the power extraction. The focus of the present work is to share results achieved in the developed of an horizontal wind turbine model test bench in wind tunnel facilities, inspired in wind turbine tunnel test bench described in Saha et al., 2008 and Jeon et al., 2015 . We present the experimental setup of the DHAWT wind tunnel model test, the performing dimensionless power curve of DHAWT model and discussion of results.

2. EXPERIMENTAL SETUP

The testing was performed in the wind tunnel of FING-UdelaR, an open loop wind tunnel with a working section of 2.25 m by 1.8 m. Test bench is designed for a 5 % of blockage area of the model, three wind turbine configuration were tested, i) wind turbine rotor without concentrating duct and without diffuser, ii) DHAWT with concentrating duct and without diffuser iii) DHAWT with concentrating duct and with diffuser. In figure 1 it is shown a lateral view of the test bench installed in the wind tunnel, number in figures correspond to component description, 1)concentrating duct, 2) diffuser 3)torque-meter Interface T25 4) magnetic powder brake.

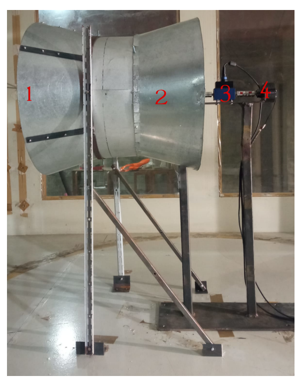

Figure 1. DHAWT model instaled in the wind tunnel test bench, lateral view, 1)concentrating duct, 2) diffuser 3)torque-meter Interface T25 4) magnetic podwer brake.

2.1. Wind Tunnel wind turbine models test bench

In order to characterize the operation DHAWT models, it is necessary to calculate the mechanical power in axis we measure the torque, the speed of rotation, on the other hand, the kinetic energy available in the flow must be calculated, for which the velocity of the incident flow and temperature is measured. Rotational speed and the torque, is measured with a torque-meter Interface T25. The tunnel air flow velocity is measured using a pitot tube, temperature is measured with a PT100 sensor. To impose the brake torque on the DHAWT axis of rotation, a magnetic powder brake is used. During test, the wind speed in the wind tunnel is imposed, then a range of values of brake torque is imposed, the process is repeated by varying the wind speed in the wind tunnel.

2.2. DHAWT model configuration.

In figure 2 it is shown the DHAWT model frontal view. The rotor is conformed by NACA4412 airfoils, the external diameter was 40 cm, the length of the airfoil ($l(mm)$) and the blade angle $\beta_b(^o)$is presented in table 1 for each radius of design. The nose of the rotor is conformed by a semi-sphere of 7 cm of diameter. The diameter relation in the concentrating duct and in the diffuser were 1.25, with a angle of conformation of both pieces of 15 degree.

Radius (mm)	56,3	83,9	104,5	121,7	136,7	150,2	162,6	174,1	184,9	195,1
$l(mm)$	44,3	35,1	30	26,8	24,4	22,7	21,2	20,1	19,1	18,3
$\beta_b(^o)$	22,6	15	11,1	8,6	6,9	5,6	4,5	3,7	3	2,4

Table 1. Wind turbine rotor dimension airfoil NACA 4412.

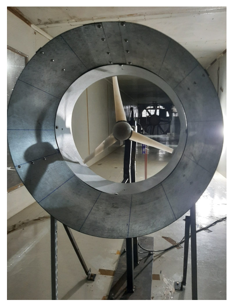

Figure 2. DHAWT model instaled in the wind tunnel test bench, frontal view.

3. RESULTS

We present dimensionless approach, it is computed power coefficient C_P (eq 1) and the tip-speed ratio λ (eq 2) for each operation tested pint. Where T and ω are the measured torque (Nm) and axial revolution velocity (rad/s) respectively, ρ the air density, A the rotor blade sweep area, R the outer rotor ratio and V_C the velocity corrected by the wind tunnel blockage coefficient proposed by Paraschivoiu, 2002.

$$C_P = \frac{T\omega}{\frac{1}{2}\rho A V_C^3} \tag{1}$$

$$\lambda = \frac{R\omega}{V_C} \tag{2}$$

In figure 3 it is presented dimensionless power curves; blue configuration i) rotor without concentrating duct and without diffuser, red; configuration ii) DHAWT with concentrating duct and without diffuser, black; configuration iii) DHAWT with concentrating duct and with diffuser. The concentrating tube did not improve the performance of the wind turbine alone, configuration ii) and iii) show a relative lower C_P. The increasing in pressure that is produced in blade swept area could be the reason of a possible boundary layer separation in the concentrating tube that make the contraction line of flux not effective. For the analyzed configurations, the full DHAWT model with concentrating duct and diffuser show lower C_P values.

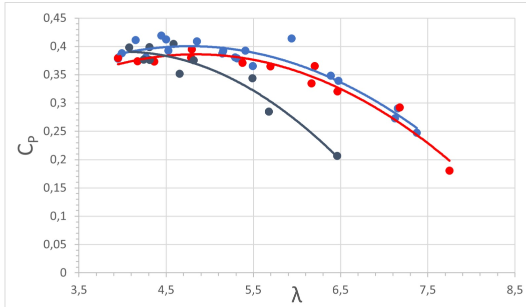

Figure 3. Dimensionless model power curves, dot represent experimental points, line polynomial best fit, blue configuration i), red configuration ii), black configuration iii).

4. CONCLUSIONS

DHAWT model test bench in wind tunnel was implemented. Concentrating duct did not improve the performance of wind turbine, it is inferred this configuration could increase the drag produced by boundary layer separation in duct. The DHAWT model with concentrating duct and diffuser show lower values of C_P, it is possible that for the configuration tested, each pieces, concentrating duct and diffuser could increase the drag and dissipation produced by vorticity. Further analysis with other diameter relation of concentrating duct and difusser need to be tested in order to obtain more generic conclusions.

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REFERENCES

Bontempo, R. and Manna, M., 2016. Effects of the duct thrust on the performance of ducted wind turbines. Energy 99, 274–287.

Hansen, M., Sørensen, M., and Flay, R., 2000. Effect of placing a Diffuser around a wind turbine. Wind Energy 3, 207–213.

Igra, O., 1977. Compact Shrouds for wind turbines. Energy Conversion 16, 149–157.

Jeon, K. S., Jeong, J. I., Pan, J.-K., and Ryu, K.-W., 2015. Effects of end plates with various shapes and sizes on helical Savonius wind turbines. Renewable Energy 79, 167–176.

KC, A., Whale, J., and Urmee, T., 2019. Urban wind conditions and small wind turbines in the built environment: A review. Renewable Energy 131, 268–283.

Lilley G. M.; Rainbird, W. J., 1956. *A preliminary report on the design and performance of ducted windmills*.

Oman RA Foreman KM, G. B., 1973. *Investigation of diffuser-augmented wind turbines - part II technical report.*

Paraschivoiu, I., 2002. Wind Turbine Design, With emphasis on Darrieus Concept. 4th ed. École Polytechnique de Montréal, Montréal, Canada.

Saha, U., Thotla, S., and Maity, D., 2008. Optimum design configuration of Savonius rotor through wind tunnel experiments. Journal of Wind Engineering and Industrial Aerodynamics 96, 1359–1375.

Sharpe, T. and Proven, G., 2010. Crossflex: Concept and early development of a true building integrated wind turbine. Energy and Buildings 42, 2365–2375.

Škvorc, P. and Kozmar, H., 2021. Wind energy harnessing on tall buildings in urban environments. Renewable and Sustainable Energy Reviews 152, 111662.

Stathopoulos, T., Alrawashdeh, H., Al-Quraan, A., Blocken, B., Dilimulati, A., Paraschivoiu, M., and Pilay, P., 2018. Urban wind energy: Some views on potential and challenges. Journal of Wind Engineering and Industrial Aerodynamics 179, 146–157.