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PRELIMINARY BLADE LOADS ANALYSIS AND PERFORMANCE OF AN URBAN SMALL POWER VERTICAL AXIS WIND TURBINE

Raluca Dora IONESCU, Ioan SZÁVA, Mircea IVĂNOIU

Abstract: *In this paper are analyzed the performances and torque magnitudes for a small power Vertical Axis Wind Turbine (VAWT).Starting from the Darrieus rotor, and applying a simplified analytical model, are determined the characteristic parameters of the design. The aim of the study is to investigate the influence of the geometric parameters and of the aerodynamic profile on the turbine power curve and on the torque distribution along the height of the turbine. This article is presenting the first step in the optimization of a new VAWT design. The study concludes that the moment distribution along the rotor height can be improved by changing several parameters.*

Keywords: *Vertical Axis Wind Turbine (VAWT), power curve, turbine torque*

1. INTRODUCTION

The urban environment comes with additional challenges when implementing a wind turbine. Several studies have been conducted in order to define the characteristics an urban-implemented VAWT should fulfill.

The first result of the studies is the need of a turbine which can function in turbulent and unsteady wind conditions. Other requirements are: also it needs good self-starting capabilities, to be silent and vibationless. Thus, a thorough study regarding the influence of the geometric parameters, as well as of the aerodynamic profile, on the turbine performances is needed.

This study aims to determine the power curve and torque characteristics for a classical Darrieus design, as a first step in the optimization of a new urban VAWT rotor.

2. ANALYTHICAL MODEL

In order to study the turbine behaviour and the torque characteristics, a simplified analytical model has been chosen. The simplest analytical model has been developed by Strickland, then it was continued by Wilson-Liesseman [1] and Paraschivoiu [2], who introduced the DMS (Double-disk multiple streamtube) model [6].

In our model, starting from the Wilson Liesseman single actuator theory (Fig. 1), together with the BEM (Blade Element Momentum) an Excel algorithm has been created. At this simplified model have been added the improvements brought by [5] regarding the blade aspect ratio as well as an improved Cp calculus that takes into consideration the stall influence and the aerodynamic profile influence depending on Re (Reynolds) number developed for the purpose of this article study. The shortcomings of the model are: it uses only symmetric airfoils, and it does not consider the blade skewness, thus we can use only straight blades.

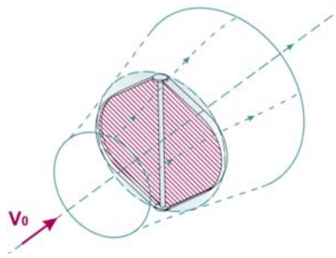

Fig. 1. Single actuator, single streamtube model.

The model has as input data the rotor geometry, the airfoil lift and drag, wind speed or TSR (tip speed ratio), the solidity; and as output, we get the power curve in terms of power coefficient (Cp-TSR) and the moment coefficient (Cm-H).

The power coefficient formula according to [5] is:

$$C_P = \frac{k\sigma x}{\pi}\cos\delta\left[\frac{\pi}{2} - \frac{4}{3\pi}k\sigma x\cos\delta + \frac{3}{32\pi}(k\sigma x\cos\delta)^2\right] \quad (1)$$

Where: k is dependency of lift coefficient – angle of attack curve and blade aspect ratio, σ is the solidity, x the tip speed ratio (TSR), δ blade angle (Fig. 3).

And hence the torque coefficient is [5]:

$$C_M = \frac{C_P}{x} \quad (2)$$

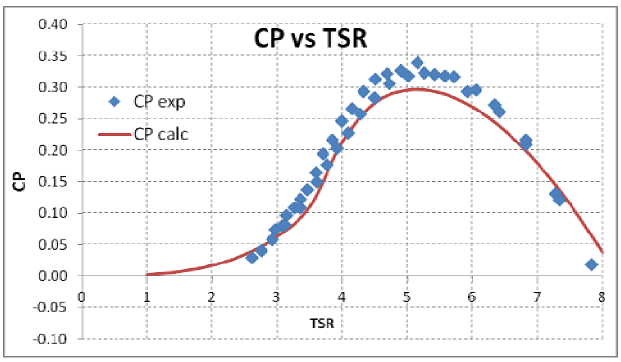

Fig. 2. Sandia 2m Darrieus validation

The first step in our analysis was to validate the model, and hence, the obtained power curve was compared with the 2m Sandia Darrieus field experimental data [7]. In Fig.2 is presented the comparison, from which we can see that the analytical model provides a good-enough approximation, and thus valid results for our study.

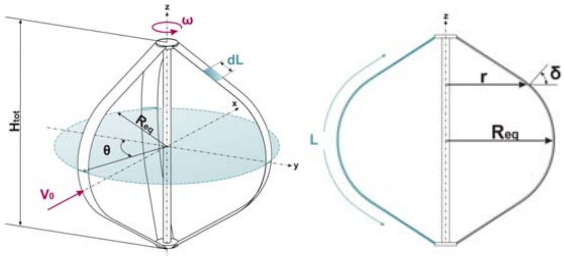

Fig. 3. Geometric parameters for a Darrieus

3. ANALYSIS RESULTS

After validating the simplified analytical model, has been passed to the analysis of a new classical Darrieus rotor. The design parameters, from previous predimensioning studies are: 2.5 *m* height (*H*), 1 *m* radius (*R*), parabolic shape blade (with the undimensional coordinates taken from Paraschivoiu [2]), 3 blades (*N*), NACA 0018 aerodynamic profile, and 0.16 *m* chord (*c*).

The blade aerodynamic profile data – lift coefficient (Cl) and drag coefficient (Cd), function of Re number - has been taken from Timmer [3] (Fig. 3).

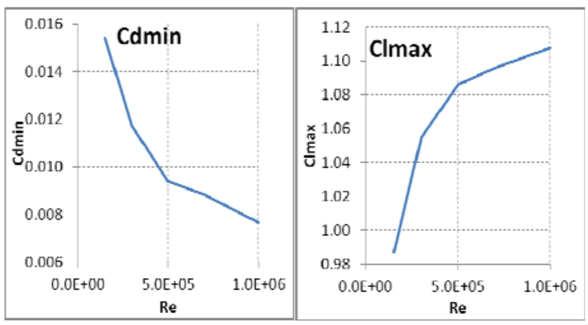

Fig. 3. NACA0018 Cl-Cd

Thus, the power curve for the new turbine is analyzed. An optimization of the rotor, in terms of solidity – chord length, has been performed, leading to the results presented in Fig. 4.

Three different solidities have been investigated. From the results can be seen that by increasing the solidity we can obtain, with minor Cp_{max} changes, a decrease in TSR value corresponding to the Cp_{max}, and hence a reduction in noise, which is very important in urban environments [4]. Thus, for the chosen solidity values, the Cp_{max} is:

Solidity	Cp_{max}	TSR
0.2	0.322	5.0
0.4	0.336	3.4
0.5	0.332	3.0

Table 1. Solidity – Cpmax values

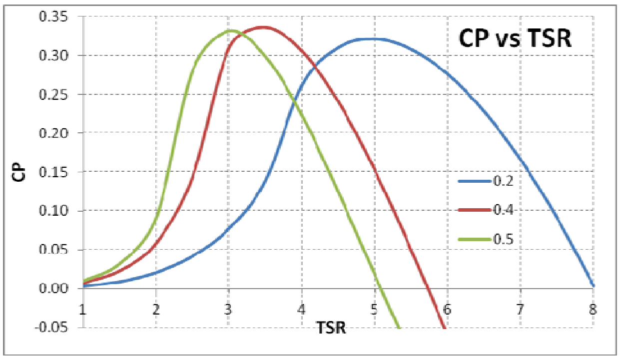

Fig. 4. New Darrieus rotor power curve

Hence, the best solution obtained is with a solidity of 0.4 that gave a chord length of 0.13*m*. The solidity of 0.5 provided a bigger chord value, of 0.16*m*.

As the purpose of our study is mainly the vibration-reduction structural optimization, and not only the aerodynamic improvement, the next step in the analysis consisted in investigating the torque values along the rotor height for the two solidities values (i.e. 0.4 and 0.5).

In Fig. 5 and 6 are presented the results with the normalized torque along the rotor height. In Fig. 5 are shown the results for the 0.4 solidity rotor, at TSR values of: 2, 3, 4, 5 and 6. It can be seen that the torque remains positive along the whole height until 5 TSR, and hence almost in all the functioning TSR range of the rotor (see Fig. 4).

In Fig. 6. Are presented the values for the 0.5 solidity rotor. It can be seen that at small TSR the torque is higher than for the 0.4 solidity rotor, but, as the TSR increases (>3), the torque decreases.

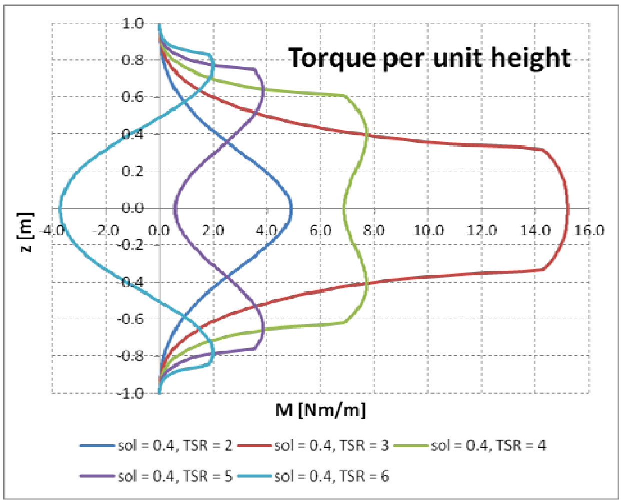

Fig. 5. Torque for 0.4 solidity Darrieus

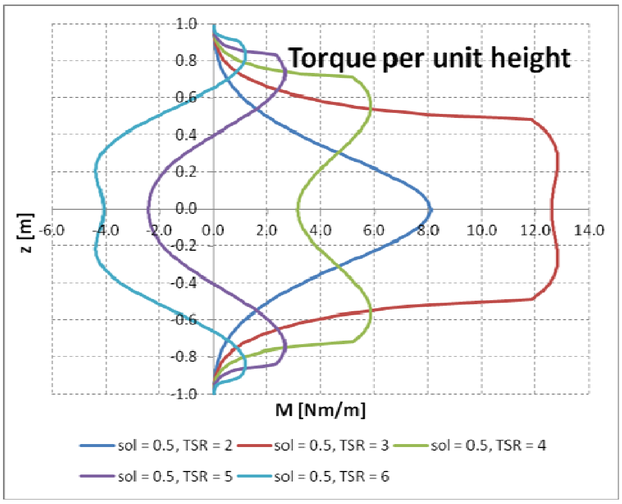

Fig. 6. Torque for 0.5 solidity Darrieus

4. CONCLUSIONS

The study aimed to determine the optimal rotor design, both in terms of aerodynamic performance, as well as in torque characteristics.

From the results, it was seen that solidities of 0.4 or 0.5 are giving better performance at lower TSR.

Hence, the two solidities were investigated from the torque characteristics point of view. It can be seen that, even if at higher TSR values, the 0.4 solidity gives a higher torque, at lower TSR the higher solidity has better characteristics. This means, that a higher torque at lower TSR values provides better self-starting behavior of the rotor. It is known that in urban environment the average wind velocities are relatively small (2-5 m/s), and thus, a higher torque at smaller TSR values is preferred.

In conclusion, from the study, the best rotor design was determined to be the one with solidity of 0.5.

This is just the first step in the analysis, and the results are based on a simplified theory. Hence, a further investigation it is needed in order to establish the optimal Darrieus design.

5. ACKNOWLEDGEMENTS

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6. BIBLIOGRAPHY

[1] Wilson, E. R., Lissaman, P. B. S., Applied aerodynamics of wind power machines; Oregon State University, 1974.
[2] Paraschivoiu, I., Wind Turbine Design with emphasis on Darrieus Concept, Polytechnic Internatioinal Press, 2002, ISBN 2-553-00931-3.
[3] Timmer, W.A., Two-dimensional low-Reynolds number wind tunnel results for airfoil NACA 0018,, Wind Engineering Journal, Vol. 32, No.6, 2008, pp 525-537, ISSN 0309-524X.
[4] Mertens, S., Wind Energy in the Built environment. Concentrator effect of buildings. Multi-Science, 2006, ISBN 0906522-35-8.
[5] Battisti, L., Wind Turbine Power Plants (Gli Impianti Motori Eolici), Green Place Energies, 2011, ISBN 978-88-906397-0-8.
[6] Ivănoiu, M., Turbine eoliene cu ax vertical (VAWT) Modele istorice ale transferului energetic, Editura Universității Transilvania Brașov, 2013, ISBN : 978-606-19-0310-8, 207 p.
[7] Sheldahl, E. R., "Comparison of Field and Wind Tunnel Darrieus Wind Turbine data", SAND80-2469, 1981.

STUDIUL PRELIMINAR AL INCARCARILOR PE PALE SI AL PERFORMANTELOR UNEI TURBINE EOLIENE URBANE, DE MICA PUTERE, CU AX VERTICAL

Rezumat : In aceasta lucrare sunt analizate performantele si valorile momentului pentru o turbina eoliana cu ax vertical (VAWT). Pornind de la rotorul de tip Darrieus, si aplicand un model analitic simplificat, sunt determinati parametrii caracteristici de design. Scopul studiului este de a investiga influenta parametrilor geometrici si a profilului aerodinamic asupra curbei de putere a turbinei si asupra distributiei momentului de-alungul inaltimii rotorului. Articolul prezinta primul pas in optimizarea unei noi turbine cu ax vertical. Studiul concluzioneaza ca distributia momentului de-alungul inaltimii poate fi imbunatatita prin modificare anumitor parametrii.

Raluca Dora IONESCU, PhD. Stud., Eng., Department of Mechanical Engineering, , Transylvania University of Brasov, E-mail: idora@unitbv.ro, Tel: (+)40.268.408.992;
Ioan SZÁVA, Prof. Dr. Eng., Department of Mechanical Engineering, Transylvania University of Brasov, E-mail: janoska@clicknet.ro, Tel: (+)40.268.408.992.
Mircea IVĂNOIU, Prof. Eng., Department of Mechanical Engineering, Transylvania University of Brasov, E-mail: ivanhoe@unitbv.ro, Tel: (+)40.268.408.992.