TECHNICAL UNIVERSITY OF CLUJ-NAPOCA

ACTA TECHNICA NAPOCENSIS

Series: Applied Mathematics, Mechanics, and Engineering

Vol. 57, Issue III, September, 2014

FORCES AND TORQUE ANALYSIS OF AN URBAN SMALL POWER VERTICAL AXIS WIND TURBINE (NUMERICAL RESULTS)

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***Abstract*:** *This paper continues the optimization of a new classical Darrieus rotor. After determining the geometrical characteristics of the new rotor, in this article has been passed to the analysis of torque, torque coefficient and rotor forces. The aim of the study is to investigate the efficiency or necessity of additional geometrical and aerodynamic changes on the torque and resultant rotor forces. Thus was investigated the addition of flaps to a part of the rotor. The study concludes that the torque variation in one turn can be improved by adding flaps.*

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

1. INTRODUCTION

For an urban wind turbine, besides the already mentioned requirements (the need of a turbine which can function in turbulent and unsteady wind conditions, it needs good self-starting capabilities, to be silent and vibationless) that it should fulfill, a very important aspect is the torque at the rotor exit, that it is transmitted to the building [4]. Thus, a thorough study regarding the influence of the geometric parameters, as well as of the aerodynamic profile, on the turbine behaviour, it is needed.

This study aims to determine the torque characteristics and resultant forces for a classical Darrieus [7], as a part of the optimization process of an urban VAWT rotor.

2. ANALYSIS PREMISES

An simplified analythical model has been used, based on Wilson-Lissaman theory [1], and improved with blade aspect ratio [5, 6] as well as an improved Cp calculus that takes into consideration the stall influence and the aerodynamic profile influence depending on the Re (Reynolds) number developed for the purpose of the study.

The new Darrieus rotor input parameters 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.

The study provided important results regarding the influence of rotor solidity on the power curve and on the torque at different tip speed ratios (TSR). It was concluded that a solidity of 0.5, (corresponding to a 0.16 *m* chord length) is the best choice for the new design, both in terms of rotor performance (Cp_{max} = 0.332 at TSR = 3, Fig. 1) as well as in self-starting capabilities (higher torque at lower TSR, Fig.2).

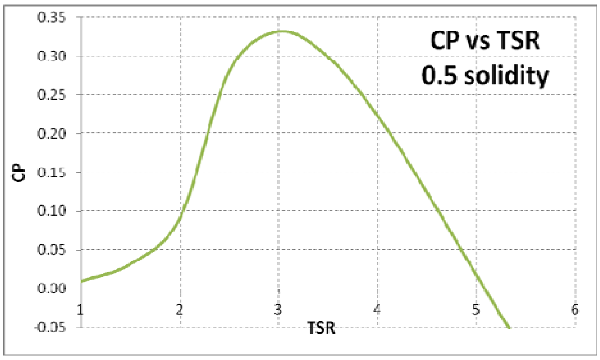

Fig. 1. New Darrieus rotor power curve

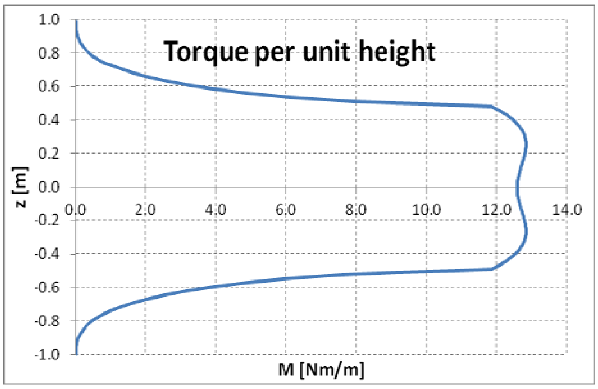

Fig. 2. Torque – normalized height at 0.5 solidity and TSR = 3

3. TORQUE ANALYSIS OF SIMPLE DARRIEUS ROTOR

The analysis has been performed in a wind-turbine BEM (Blade-Element Momentum) analysis, free software, QBlade [8, 9]. The software is based on the double-multiple streamtube theory by Paraschivoiu [2] and uses as airfoil solver the XFoil analysis tool [10] for determining the aerodynamic profile characteristics. Xfoil solves the profile up to stall, and after, QBlade extends the properties by extrapolating data for the 360 degrees polar angle of attack (AOA) with the model of Montgomerie or Viterna-Corrigan – in our study has been used the Montgomerie method. The analysis, for all the cases, has been performed at a Reynolds number of 150000.

First has been analysed the simple rotor torque coefficient at two TSR values: 3 and 4.

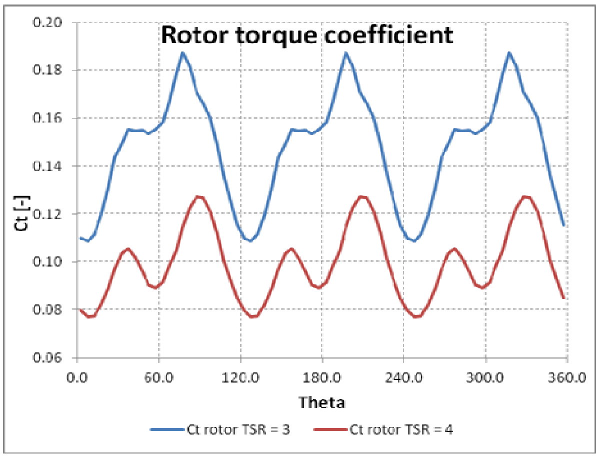

Fig. 3. Rotor torque coefficient function of theta

It can be seen that by increasing the TSR value, the torque coefficient decreases and its characteristic becomes more even.

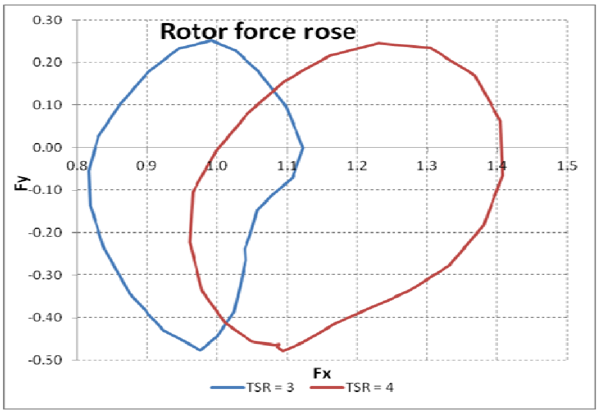

Fig. 4. Rotor forces lengthwise (x), crosswise (y)

In Fig. 4 we can see that increasing the TSR, the lengthwise forces magnitudes are also increasing.

Considering the distribution of torque from Fig.2, an investigation of torque variation along the normalized height has been performed (Fig.5). From it we can see the distribution at the end of the blades (0.020), in the upper half middle (0.173) and near the equatorial plane (0.429).

Hence, an improvement in the blades ends has been proposed.

In Figure 6 are presented the torque characteristics at two different wind speeds, for two rotation velocities. The 270 *rpm* constant rotation velocity is corresponding, for our design, to a 9 *m/s* wind velocity, and the 134 *rpm* is corresponding to a 5 *m/s* wind speed.

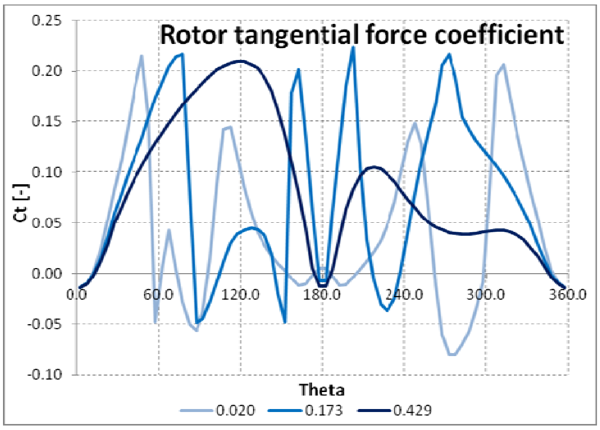

Fig. 5. Rotor tangential force coefficient for three normalized heights.

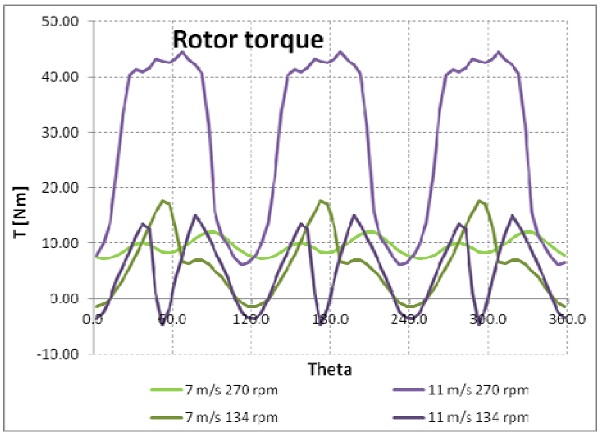

Fig. 6. Rotor torque at different rpm and wind speeds.

4. TORQUE ANALYSIS WITH FLAPS

In our study we aimed to improve the previously presented new Darrieus rotor design. Hence, from Figures 1 and 2 we can see that at the highest Cp_{max} value the torque has a tendency to decrease towards the rotor shaft ends, and has an almost equal value around the equatorial plane.

In conclusion, we have investigated the solutions for improving the torque characteristic near the blade ends.

Previous experimental results of the NACA0018 [3] as well as analyses performed by the authors have shown an improvement in the lift-drag airfoil polar when a 10 degree flap is added (the obtained Cl_{max}=1.4373 for the 10 *deg* flap, comparing to Cl_{max}=1.2256 for a NACA0018, at Re=150000), Fig. 7.

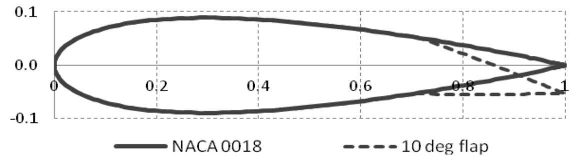

Fig. 7. NACA0018 and with 10 *deg* flap.

Thus, for improving the torque characteristics, at the ends of the blade (Fig.8) have been added flaps. The length of the flaps area is corresponding to the aimed blade length for torque improvement.

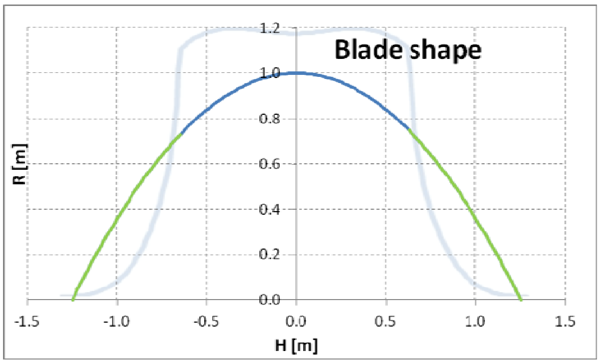

Fig. 8. Rotor blade shape and flaps areas corresponding to torque improvement target sectors

In Fig. 9 it is presented the influence of the flaps on the rotor tangential force coefficient.

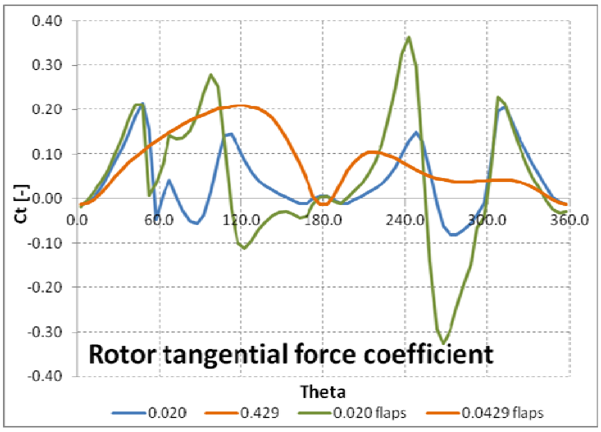

Fig. 9. Rotor tangential force coefficient with flap

And in Figure 10 is presented the influence of the flaps on the force components. It can be seen that the flaps solution is decreasing the loading of the shaft.

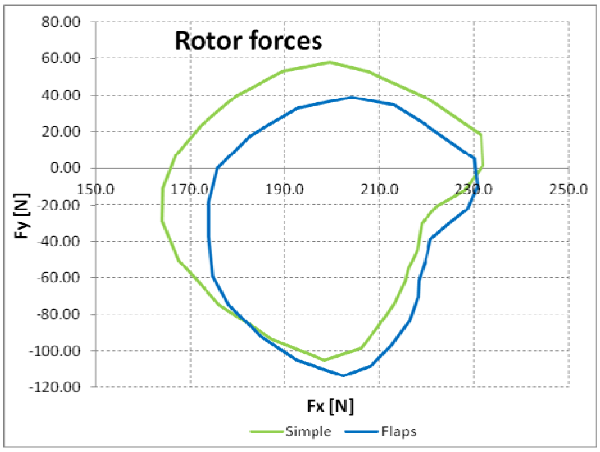

Fig. 10. Rotor forces with flaps

5. CONCLUSIONS

The study aimed to investigate the influence of flaps on the turbine torque and forces. From the results, it was seen that the flaps are increasing the value of maximum tangential force coefficient, thus providing better performances for the chosen sector.

In conclusion, from the study, the flaps solution proves to give better performances, and hence, encourages further investigations for optimising the design and reducing the loads. This is just the first step in the analysis, and the results are based on a simplified theory, thus further CFD studies are required.

6. ACKNOWLEDGEMENTS

This paper is supported by the Sectoral Operational Programme Human Resources Development (SOP HRD), ID134378 financed from the European Social Fund and by the Romanian Government.

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ANALIZA FORTELOR SI A MOMENTULUI PENTRU O TURBINA EOLIANA URBANA DE MICA PUTERE (REZULTATE NUMERICE)

Rezumat: Lucrarea continua optimizarea unui nou rotor de darrieus clasic. Dupa determinarea caracteristicilor geometrice generale ale noului rotor, in acest articol s-a trecut la analiza momentului, a coeficientului de moemnt si a fortelor. Scopul studiului este acela de a investiga eficienta sau necesitatea schimbarilor de geometrie sau de performante aerodinamice asupra momentului rezultant si aspura fortelor rotorului. Studiul concluzioneaza ca variatia momentului intr-o rotatie poate fi imbunatatita prin adaugarea flapsurilor.

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