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Analysis of the influence of the aspect ratio on the vertical axis wind rotor performance

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Abstract. The aspect ratio (AR) of the vertical axis wind rotors defined in this paper as the ratio between the height and the diameter of the rotor is an important factor when considering the performance of the rotors. However, choosing the most appropriate AR when designing a wind rotor, based on literature review, is not fully reliable as different sources point out contradictory data. This paper presents an analysis regarding the influence of the AR on rotors performance based on experimental data.

1. Introduction

As climate change is a problem of global concern nowadays, renewable energy is considered an important link from the chain of solutions that are to be applied for tackling this problem. Wind turbines represent machines that convert wind energy into electricity. Over the last few decades, they became a usual feature of the landscape in many countries. The vast majority of them are horizontal axis wind turbines (HAWTs) (figure 1). HAWTs have been heavily researched and developed until high efficiency has been achieved for the largest ones [8]. The main disadvantage of this type of turbine is that it needs a yaw mechanism that points the turbine's rotor perpendicular to the wind direction. This disadvantage is not a problem for vertical axis wind turbines (VAWTs). By design VAWTs can catch the wind coming from any direction. As a consequence, it is considered that they are better suited for electricity generation at a small scale, like covering the electricity needs for one household where minimal maintenance is desirable [7]. Though big VAWTs can reach fairly high efficiency, they are surpassed in performance by HAWTs. In this regard, more research is needed for achieving a higher efficiency as theoretically this thing is possible. This paper presents an analysis in which the performance of the straight bladed vertical axis wind turbines is related to the dimensional aspects of the turbine.

2. Theoretical background

The general formula for calculating the power output of a wind turbine is expressed as follows:

$$P = \frac{1}{2} C_p \rho A U^3 \qquad (1)$$

where P is the output power of the wind turbine; U – the wind speed before the interaction with the turbine; ρ – the air density; A – the swept area of the turbine; C_p – the performance coefficient of the turbine. C_p ranges from 0 to 1 with a theoretical maximum of 0.593 called Betz limit. Big modern

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HAWTs can reach a value of about 0.5 whereas VAWTs a maximum of 0.4. Nevertheless, Paraschivoiu [4] writes that for VAWTs a maximum of 0.64 can be theoretically reached.

Figure 1. VAWT (Quiet Revolution) and HAWT (Technical University of Moldova).

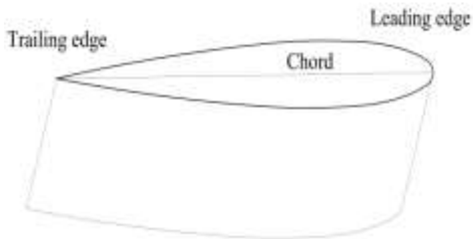

Figure 2. The blade's chord.

As can be noticed from the formula (1) the power output of the turbine is directly proportional to the swept area A. However, for the same area there could be different shapes. The shape of the swept area is characterized by the Aspect Ratio (AR) of the rotor. More precisely the AR is defined as:

$$AR = \frac{h}{D}, \quad (2)$$

where h is the height of the rotor, (for the straight bladed wind turbine the height of the rotor is the same as the blade's length) and D is the diameter of the rotor. When designing a vertical axis wind turbine one can ask which aspect ratio is the best for a higher power output or if the aspect ratio is of any importance at all. As it turns out, choosing a specific aspect ratio will influence the performance of the turbine and the energy output respectively.

The recommendations regarding AR seem to be contradictory. For example, Brusca [1], defining the aspect ratio in the same way as in the equation (2), recommends a smaller AR for the turbines, as this facilitates a higher Reynolds number. The authors have done their analysis using the Multiple Streamtube Model proposed by Strickland [2]. On the other hand, Ionescu [3] recommends a smaller AR but defining it as the ratio between the diameter and the height of the rotor (D/h). Ionescu's analysis was done using the software QBlade which is based on Double Multiple Streamtube Model developed by Paraschivoiu [4]. Both models are based on the same principles.

When analyzing the AR, there can be two options or rather directions. One can analyze the influence of the aspect ratio on the turbine performance by keeping the solidity of the rotor constant or by keeping the length of the chord constant. The chord (c) is defined as the line connecting the leading edge of the blade's cross section with the trailing edge (figure 2). For the straight bladed VAWT, the solidity (σ) is defined as the ratio between the sum of the chord lengths of the three blades and the diameter of the rotor:

$$\sigma = \frac{3c}{D}. \quad (3)$$

This paper presents the analysis of the aspect ratio influence on the straight bladed vertical axis wind turbine's performance by keeping the length of the chord constant. Three turbines are analyzed, each one having a different set of lengths for the diameter and height of the rotor but the same swept area. The schematic configurations are presented in the figure 3.