Kinematics of a vertical axis wind turbine with a variable pitch angle

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Abstract

A computational model for the kinematics of a vertical axis wind turbine (VAWT) is presented. A H-type rotor turbine with a controlled pitch angle is considered. The aim of this solution is to improve the VAWT productivity. The discussed method is related to a narrow computational branch based on the Blade Element Momentum theory (BEM). The paper can be regarded as a theoretical basis and an introduction to further studies with the application of BEM. The obtained torque values show the main advantage of using the variable pitch angle.

Keywords: vertical axis wind turbine, variable pitch angle, blade element momentum theory

1. Introduction

In the case of vertical axis wind turbines, the axis of rotation is perpendicular to the direction of the undisturbed airflow. Consequently, the turbines can operate independently on wind direction, they do not have certain complicated components (the yaw system), and the heaviest components (e.g. generator) may be located on the foundation. Thus, the overall cost is lower in comparison with horizontal axis wind turbines (HAWT) [2]. The benefits may be especially attractive to a new group of clients: individuals, small businesses, local governments and housing associations, willing to deal with microgeneration of electric power from renewable resources. One of the main disadvantages of VAWTs is their efficiency, lower than in the case of HAWTs. The most promising and efficient VAWT is the H-type rotor turbine (a special case of the Darrieus rotor, see Fig. 1) [2].

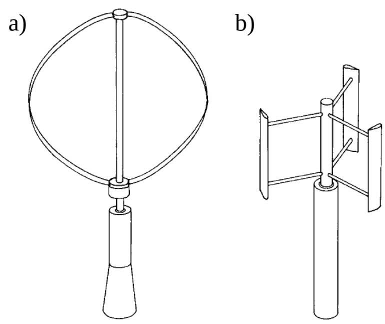

Figure 1: VAWT: a) Darrieus rotor, b) H-type rotor [2]

2. Formulation of the problem

Calculation of the power generated by a turbine requires application of the blade element momentum theory [3]. The studies are restricted to a narrow area of the theory, related to the tangential forces acting on a rotor blade at a given airflow velocity around the turbine.

For the discussed rotor type, the driving torque results from a sum of the tangential components of lift and drag on the blades [1]. The forces depend on the blade profile, the Reynolds number, air density and the pitch angle. The H-type rotor has a constant cross-section along its axis of rotation, hence, the computational problem can be reduced to two dimensions.

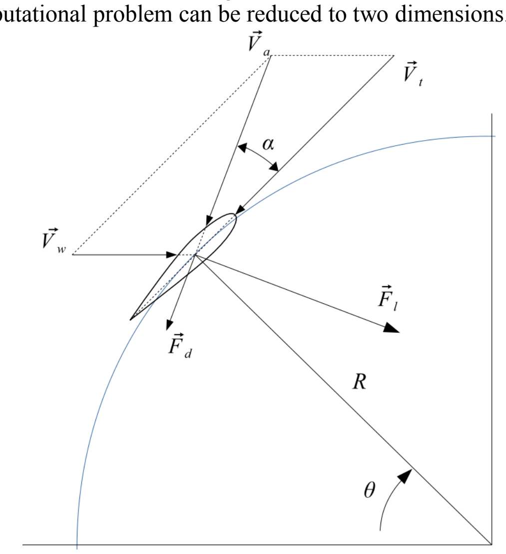

Figure 2: Kinematics of the Darrieus type VAWT

A sum of the blade velocity $\vec{V}_t$ and the wind velocity $\vec{V}_w$ gives a vector corresponding to the relative motion of the blade with respect to air mass:

$$\vec{V}_a = \vec{V}_w + \vec{V}_t \tag{1}$$

Thus, the angle between this vector and the tangential velocity is the pitch angle, α (Fig. 2). The torque value for any angular configuration is given by

$$\tau = \left(F_l \sin\alpha - F_d \cos\alpha\right) R \tag{2}$$

where F_l and F_d denote the lift and drag forces, while R is the rotor radius. The both forces can be expressed as:

The research has been supported by Polish Ministry of Science for young scientists (decision no. 8710/E-362/M/2017).

$$F_l = \frac{1}{2} C_l \rho A V_a^2 \quad \text{(3a)}$$

$$F_d = \frac{1}{2} C_d \rho A V_a^2 \quad \text{(3b)}$$

where C_l and C_d are the lift and drag coefficients, ρ is the air density, A is the area of the blade. Values of C_d and C_l changes with the pitch angle α [4]. These characteristics are widely available in literature. For the purposes of this work, the NACA 0012H airfoil has been selected. The angle α is calculated from the formula:

$$\alpha = \arccos\left(\frac{\vec{V}_t \circ \vec{V}_a}{V_t V_a}\right) \quad \text{(4)}$$

where $V_t = \omega R$. Direction of $\vec{V}_t$ is dependent on the angular position of the rotor (angle θ), thus α, τ, C_l, C_d, F_l, F_d and $\vec{V}_a$ are functions of θ (Fig. 2). The torque calculated according to formulas (1) – (4) is a value specific for a given θ. The obtained dependencies for the pitch angle, relative velocity and torque in the case of a H-type rotor with one blade are shown in Fig. 3.

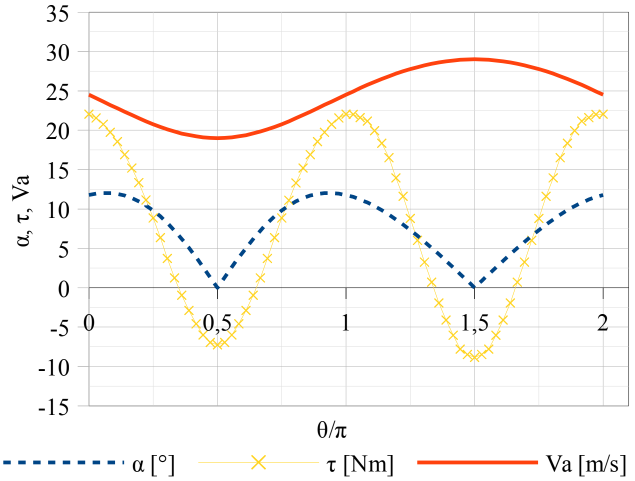

Figure 3: Pitch angle, torque and V_t for a rotor with the NACA 0012H blade profile

3. Pitch angle control

Since the pitch angle changes during rotation of the rotor, the maximal possible value of the lift force for the current position of the blade is not always achievable: the lower pitch angle, the lower C_l according to Eq. (3a). In order to counteract the effect, a H-type rotor with the pitch angle control is proposed. From the computational point of view, the task is to find such a value α' for which C_d and C_l make the torque $\tau(\theta)$ reach a maximum for a certain θ:

$$\tau(\theta) = \left(C_l(\alpha')\sin\alpha - C_d(\alpha')\cos\alpha\right)\frac{1}{2}\rho A V_a^2, \theta \epsilon \langle 0, 2\pi\rangle \quad (5)$$

Taking into account the available characteristics $C_l(\alpha)$ and $C_d(\alpha)$ for the NACA 0012H profile, the optimal pitch angle values have been determined for the rotor with a single blade (Fig. 4a). Oscillations of the torque for the conventional and the proposed variant are presented in Fig. 4b. The results have been obtained for the folllowing parameters: V_t = 24 m/s, V_w = 5 m/s, R = 5 m, the blade width s = 0.1 m, the rotor height h = 1 m.

The application of the variable pitch angle concept has lead to an increase in the average torque value from 8.12 Nm to the level of 9.96 Nm, that means an increase by 22.6%.

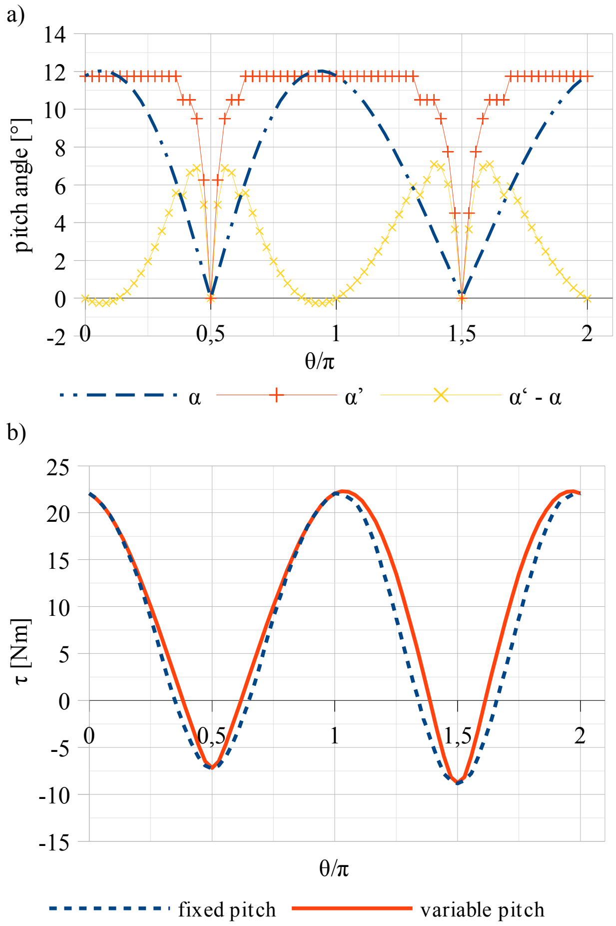

Figure 4: Results for the fixed pitch and variable pitch rotor: a) pitch angle, b) torque

4. Conclusions

The considerations presented in this paper have a preliminary nature, and they correspond just to a fragment of the computational studies based on BEM. A more developed analysis of the problem will allow one to assess the proposed approach. Nevertheless, even at this stage, the solution with a variable pitch angle seems to be promising. Future studies may require to take into account the energetic costs incurred in overcoming the inertia of blades in the control process.

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