

ARGUMENTATION OF THE GEOMETRIC PARAMETERS OF THE WIND ROTOR WITH VERTICAL AXIS

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Abstract: Wind energy currently are the most used, cheap and clean renewable energy sources. The variety of existing wind energy conversion systems can be grouped into two distinct classes: horizontal (HAWTs) and vertical (VAWTs) wind turbines. The main goal of this paper consists in the mathematical modeling of the aerodynamic profiles of VAWTs blades. This paper describes the steps of elaboration of calculation model for dynamic simulation of a small vertical axis wind turbine rotor. The calculation model is based on the finite element analysis ANSYS CFX software. The CFD model is used to determine the performance of the wind turbine rotor. A new design and functional concept of VAWTs was proposed, patented and elaborated.

Keywords: Aerodynamic profile, wind turbine with vertical axis (VAWT)

1. Introduction

One of the greatest challenges of the 21st century is to ensure the access of every citizen of the Planet to sustainable, non-polluting energy. Today, we speak of a global energy policy and a concerted strategy to reduce harmful emissions into the atmosphere. 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 energies are the oldest form of renewable energy used by man and has become the most currently used renewable energy sources, being also one of the best, cheap and clean energy sources.

Wind is environmentally friendly but today they are not able to meet these ever-growing needs. The variety of existing wind energy conversion systems can be grouped into two distinct classes: horizontal (HAWT) and vertical (VAWT) wind turbines. HAWTs have been heavily researched and developed until high efficiency has been achieved for the largest ones [1]. Compared to HAWT, vertical axis wind turbines (VAWT) have a number of advantages: they do not require a wind direction orientation mechanism; lightly servicing the generator and multiplier (if applicable) located at the bottom of the turbine; reduced (comparable to HAWT) turbine tower demand; ensures relatively high conversion efficiency in turbulent areas of air currents (urban and suburban areas).

An important tool in engineering that generally lead to cost and time savings during product development are simulations [2]. Finite element analysis serves as a base for the present work. Besides choosing the appropriate mathematical model behind physics of the simulated system, it is important to choose the right shape and size of the finite elements. It is also important that the elements are well adapted for the specific system to be analyzed.

A modern research has the following structure (fig. 1). IHP is equipped with modern Workstations

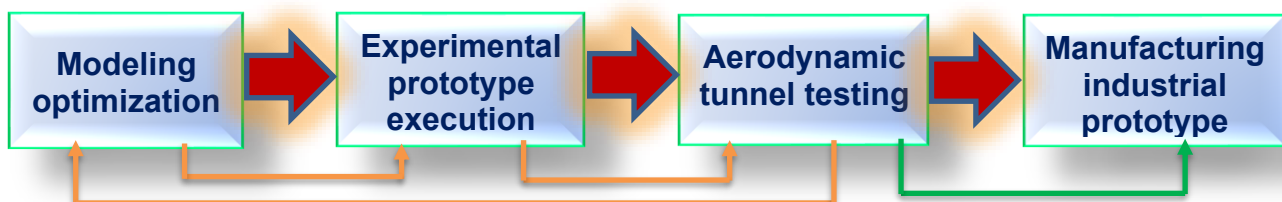


Fig. 1. The structure of modern research

and performance simulation software ANSYS; 3D printer (fig. 2); human potential.

This work presents a CFD model created for determining the performances of a vertical axis wind turbine. The CFD model is made using ANSYS CFX software. The CFD model is used to determine the power curve of a 0.5 kW modeled wind turbine. For this power there are wind turbines developed by several companies. Comparison of the simulated wind turbine power output with real wind turbines power output is considered as validation of the CFD model.

The stages of CFD simulation of the wind and hydraulic rotors are shown in ANSYS Workbench Project schematic (fig. 3).

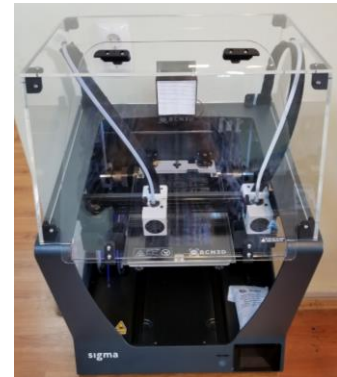


Fig. 2. 3D printers for manufacturing

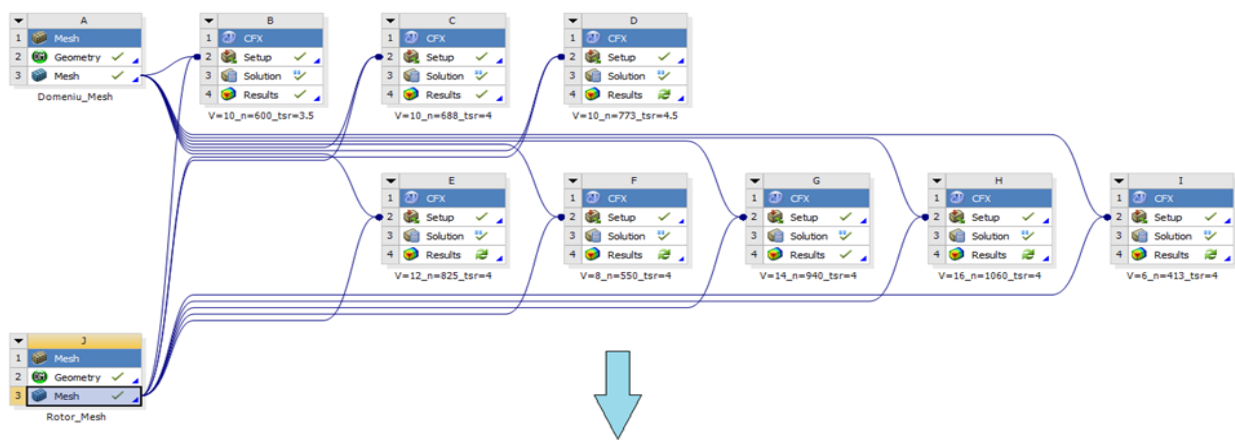


Fig. 3. ANSYS Workbench Project schematic

2. Rotor's geometry and fluid domain modeling and meshing

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

$$P = \frac{1}{2} C_P \rho A V^3 \quad (1)$$

where P is the output power of the wind turbine;

V – 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 HAWTs can reach a value of about 0.5 whereas VAWTs a maximum of 0.4. Nevertheless, professor Ion Paraschivoiu from Ecole Polytechnique de Montreal unknown specialist in the field of VAVTs, writes that for VAWTs a maximum of 0.64 can be theoretically reached [3]. The chord of the turbine blade is 0.11m, though more chord lengths were analyzed. The helical angle of the blades is 60°. The rotor geometry, designed using SolidWorks (fig. 4), was then imported into the ANSYS DesignModeler software. The

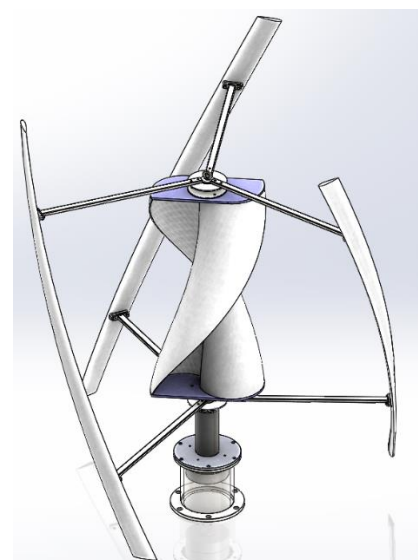


Fig. 4. The rotor geometry

dimensions of the computational fluid domain were chosen taking into account the recommendations of [4] so that the boundaries of the field do not influence the free flow of the air. The simulated fluid domain was divided into two subdomains: the Stator (static) subdomain and the Rotor subdomain inside of it (of cylindrical form, which rotates around its axis). Figure 5, a shows the considered fluid domains. The mesh used for finite element analysis of the rotor fluid domain (fig. 5, b) and of the blade (fig. 5, c) was generated using the ANSYS Meshing Workbench.

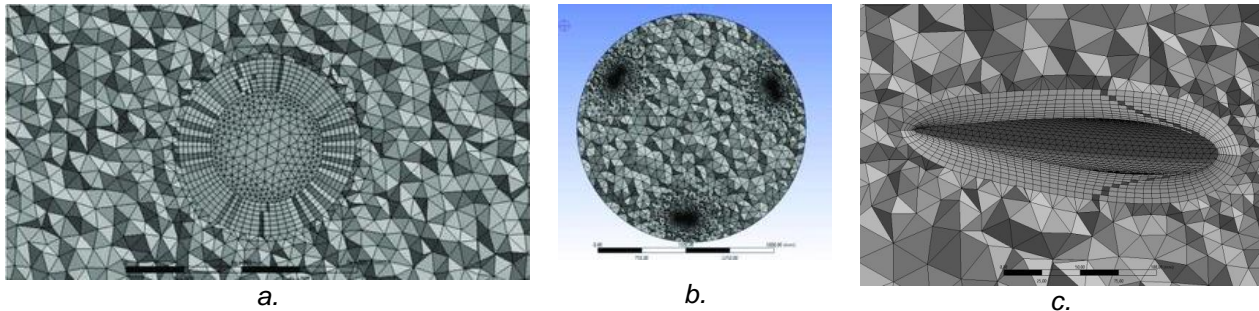


Fig. 5. Mesh used for finite element analysis

The basic dimensions of the mesh are as follow: the minimal size of the inflation around the blade = 0.5 mm and the maximum size of the side of one face = 110 mm. The transition from the fine-meshed areas to the gross meshed ones was done by specifying the Growth Rate = 1.15 expansion factor. The maximum variation of the characteristic dimensions of two adjacent elements is not bigger than 4%. The entire domain was meshed into approx. 2 800 000 finite elements.

Very important are the effects formed on the blades' surfaces where it is formed the lift and drag, also the boundary layer separation occurs and other important effects take place. The boundary layer forms, rectangular finite elements have been generated by expanding them from the surface of the blade outwards. This was done using Inflation Layer technique around blades' surfaces: number of layers = 10, the Growth Rate = 1.15 (relative thickness between two adjacent layers), and Growth Rate Type = Geometric. Figure 5, c shows the mesh details around the blade.

In order to verify the conversion efficiency of the turbine, several modes have been simulated. There were considered four different airfoils (NACA 0021, NACA 0018, NACA 0015, E168) with different parameters. Each chord length is simulated under different tip speed ratios. The wind speed considered for simulations is 12 m/s.

Surfaces of the Stator fluid domain (fig. 6) are subjected to Walls boundary conditions with the free-slip specification that simulates a zero-adhesion virtual wall. Blades surfaces are subject to Walls boundary conditions with no slip specification which does not allow mass or energy transfer. The surfaces at the intersection of the two Stator and Rotor subdomains (fig. 6) are interface surfaces of the two subdomains through the GGI method. At this stage more attention is required to certain details such as the direction of rotation of the rotor and wind direction, which can be changed with the (-) sign.

The simulations were carried out and the results are presented in figures 6-8. As a result of the multicriteria simulations performed, the distribution of air flow velocities in the middle area of the rotor (CFX-Post 12.1) was established (fig. 7, a). Also, the degree of turbulence of the air currents developed by the blades in the middle area of the rotor was established (fig. 7, a).

Turbulence developed (CFX-Post 12.1). Distribution of pressure on the rotor blades and 3-D visualization of the flow lines for the case of the wind speed of 12 m/s are presented in Figure 8 and 9, a (CFX - Post 12.1). The analysis of the obtained distribution of pressure and the flow lines allows the optimization of the blade's geometric parameters and their angle of inclination. The interaction of the blades with the air flow lines generate lift forces that actuate the rotor in rotational motion (fig. 9, b). The analysis of the diagram shows that the intensity of the power lines increases towards the middle of the turbine.

Due to the fact that the preliminary results of the numerical analysis of the rotor performance are

better for NACA 0018 airfoil (fig. 10), this airfoil has been selected for subsequent simulations. The solving of discretized equations was performed in parallel using all 16 logical cores. The goal is to obtain 0.4 – 0.5 kW of power at a wind speed of 12 m/s. First of all, optimal airfoil chord length was determined. The optimal chord length for this rotor is 0.11 m.

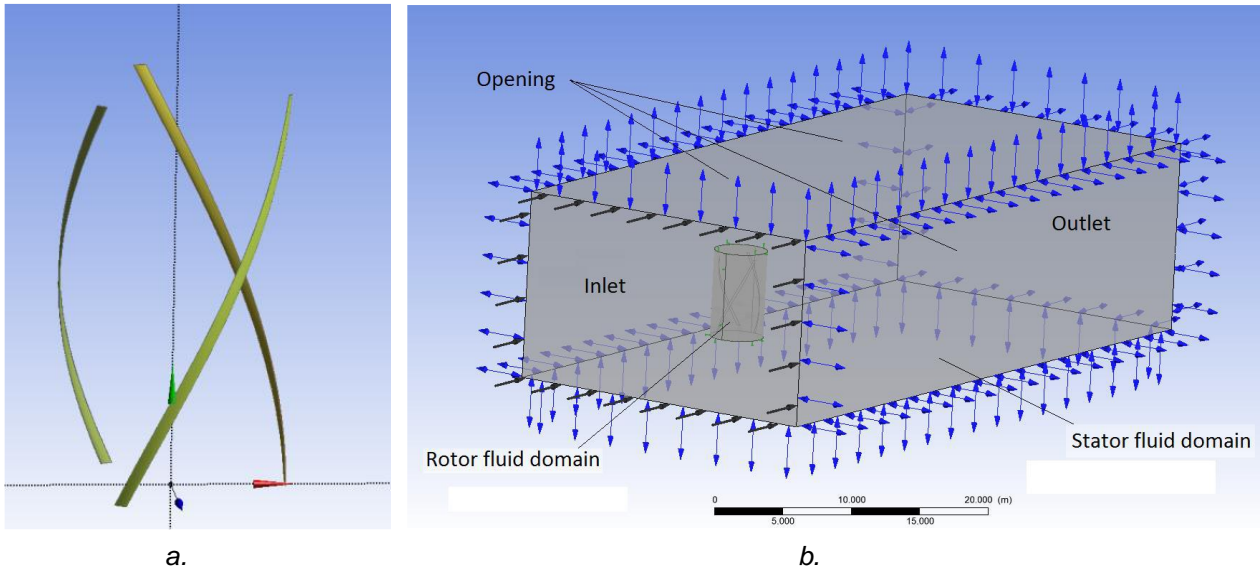


Fig. 6. Rotor geometrical model (a) and fluid domains (rotor and stator) (b).

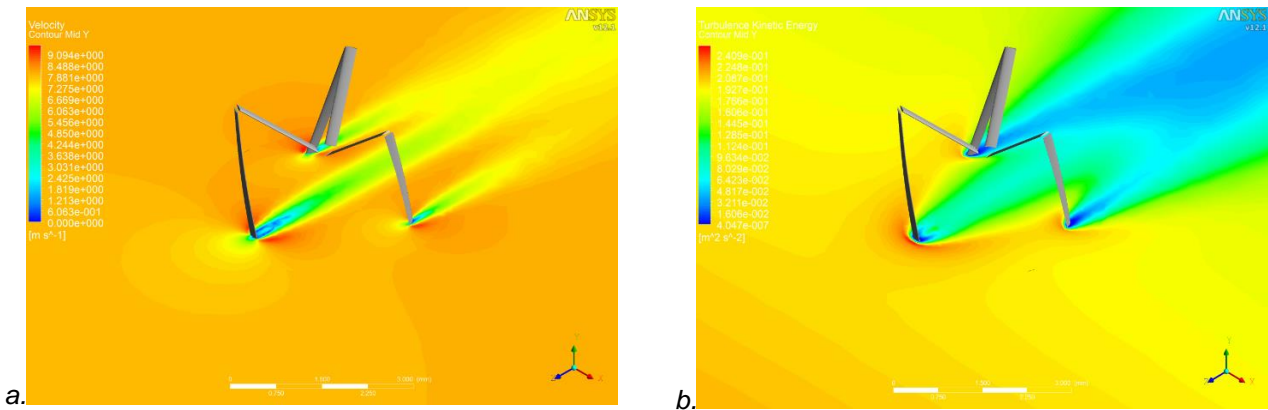


Fig. 7. Distribution of air flow velocities (a) and turbulence (b) developed by the blades in the middle area of the rotor (CFX-Post 12.1)

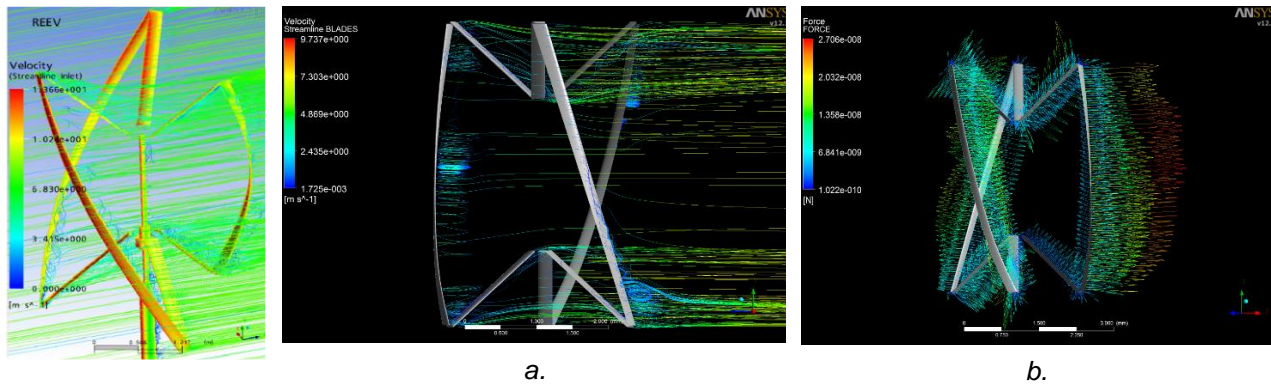


Fig. 8. Distribution of pressure and the flow lines for wind speed of 12 m/s

Fig. 9. Air lines flowing through the rotor (a) and the forces acting on the rotor (b) (CFX - Post 12.1)

The next stage was the design and manufacture by additive technologies (3D printing) of a blade segment with aerodynamic profile NACA 0018 and its testing at different wind speeds in the aerodynamic tunnel GUNT 170 from the Aerodynamics Laboratory of the Technical University of Moldova. The tests were performed for different wind speeds and different angles of

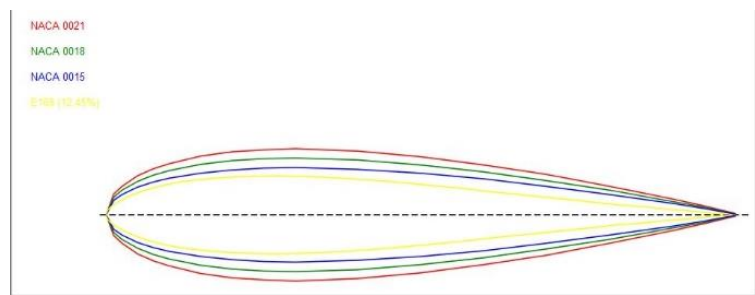


Fig. 10. Comparing airfoils.

attack, the ratio between the lift and drag forces (F_L/F_D) being determined. The results of the testing are synthesized in the figure 11. It can be noticed from the figure that this profile NACA0018 provides an optimal $F_L/F_D = 5$ ratio practically constant for the values of the angle of attack $8 - 16^\circ$ at the wind speeds $V=10-24$ m/s.

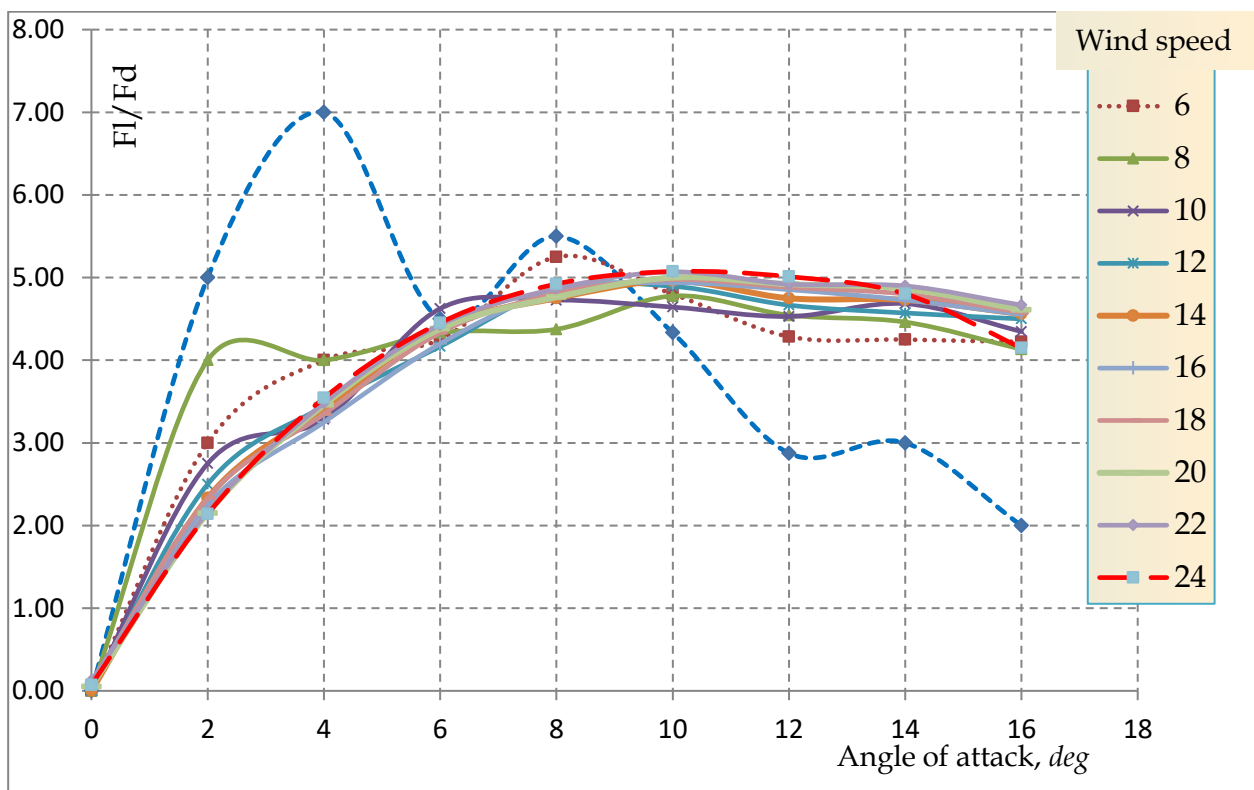


Fig. 11. Blade segment performance determined in the wind tunnel

3. Elaboration of the hybrid wind rotor with vertical axis

Based on the results of the multicriteria simulations and experimental tests performed in the aerodynamic tunnel, the optimum aerodynamic profile NACA 0018 was chosen for this rotor and the attack angle of 12° . These parameters were taken as the basis for designing the experimental prototype of the vertical axis wind turbine (fig. 4). The helical blades (the helicoidal angle - 18°) were manufactured by additive technologies in the Composite Materials Laboratory from Faculty of Machine Construction, Technical University of Cluj-Napoca. To increase the efficiency of conversion of the wind turbine with vertical axis at low wind speeds, the Darrieus rotor was supplemented with a Savonius rotor, which has the starter function. The experimental prototype of the vertical-axis hybrid wind turbine is shown on Figure 12.



Fig. 12. Experimental prototype of the vertical-axis hybrid wind turbine

Also, the stand of natural tests, the program of tests and the necessary equipment for the measurement and processing of the data were developed. The experimental prototype is to be tested in winter conditions with better wind energy potential. Based on the scientific results that will be obtained, the industrial prototype of the hybrid vertical-axis wind turbine will be designed.

4. Conclusions

1. The CFD simulation is applied on the downscaled wind rotor in order to determine the aerodynamic performances.
2. It can be noticed that profile NACA0018 provides an optimal $F_l/F_d = 5$ ratio practically constant for the values of the angle of attack $8 - 16^\circ$ at the wind speeds $V=10-24$ m/s.
3. By experimental research there were determined the performances of the downscaled blade segment based on NACA 0018 airfoil in terms of Lift over Drag forces for different wind speeds and for different angles of attack.
4. The technical documentation of the downscaled wind rotor and rotor's stand was realized.
5. Experimental research on the built downscaled wind rotor is to be carried out in the real conditions in order to determine the aerodynamic performances. The results are to be compared with the ones obtained by CFD simulation using ANSYS CFX in order to validate the CFD model used for simulating the wind rotor.

Acknowledgments

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