Aerodynamic Modeling of Generator Towers

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Abstract. *The energy produced from wind turbines is the result of a modern technology applied to the force of the wind to obtain electrical energy. The towers are large structures that guarantee clean and renewable energy and continue to expand in Brazil, with a promising scenario. According to the [1], in 2020 there was a 14.89% growth in power compared to December 2019. In the same year, 66 new wind farms were installed in the country and another 14 were repowered, totaling 2.30 GW of new capacity. The wind towers can reach up to 130 meters in height and are made of metallic or concrete material, both prefabricated and assembled in the wind farms. In this case, the present work aims to model a wind tower, using finite element software, in order to verify the influence of aerodynamic phenomena, especially the Flutter phenomenon in the wind turbine blades and its consequences on energy production. It is expected to obtain in the final result, how vibration phenomena affect the yield of electricity production in wind farms.*

Keywords: wind energy, aerodynamic, wind turbines.

1 Introduction

Currently, the need to obtain energy in a sustainable way is growing. due to the great environmental impact caused by the high consumption of fossil fuels for its generation. Aiming at this aspect, the United Nations (UN), in its 2030 agenda for sustainable development, proposed as one of its objectives to guarantee access to cheap, reliable, sustainable, and renewable energy for all. Wind energy is a renewable source that is less used compared to other technologies, because it is important, especially in the context of reducing greenhouse gasses, since it has practically zero emission rates [2]. According to [3], the variable warming of the Earth's surface by solar radiation is the main agent in the production of wind; because tropical regions have a better radiation absorption capacity than the polar regions. The topographic characteristics of a region also influence the behavior of winds, since, in a certain area, differences in speed may occur causing a reduction or acceleration in wind speed [4]. It's also important to note that the wind speed varies with height and depends fundamentally on the nature of the terrain on which the air masses move [3]. According to [4], the location where you want to install wind turbines is influenced by several regional parameters, such as speed variation with height, roughness of the ground, the relief and the presence of obstacles in the surroundings. A wind turbine transforms the kinetic energy of the wind into mechanical energy to finally transform it into electrical energy [5]. The capture of wind energy is made through the action of the wind on the blades, which are connected to the shaft through the rotor. The aerodynamic principle that allows this assembly to rotate is similar to what makes airplanes fly, because the air forced to flow through the upper and lower faces of a plate or inclined profile, generating a pressure difference between both faces, obtaining a resultant force that acts on the profile [3]. This resultant force is obtained through the combination of two forces, the lift force and the drag force. According to [4], lift forces are given when a body is acted upon by forces acting perpendicularly to the direction of flow, and the drag forces, when these forces act parallel to the flow. Although the wind load on the surface of the blades produces rotational energy, it also causes the structure to bend out of the rotational plane [6]. However, wind turbines are subject to atmospheric turbulence, wind shear, and the effects from the wake of neighboring wind turbines[7]. The aerodynamics of a wind turbine is extremely complicated and in many ways parallels the problems found with helicopter rotors, such as the challenges in understanding and predicting the unsteady blade airloads and rotor performance, as well as predicting the dynamic stresses and aeroelastic response of the blades [8]. For this reason, the study of the aeroelastic behavior of the wind turbine requires well-designed calculation models, since it considers the coupling between the flexible rotating elements (the blades), the rigid element (the nacelle), and the grounded tower structure [9].Given these circumstances, in the present work was developed a three-dimensional modeling of a horizontal axis wind turbine for the analysis of its aerodynamic behavior, implementing finite element methods (FEM), to verify the impact of these phenomena on energy production.

2 Methodology

For the development of this work, firstly, the modeling of a horizontal axis wind turbine was carried out following standardized dimensions obtained from other wind turbine projects, using the ANSYS DesignModeler software, used to run simulations of exclusive models through the creation of parametric geometries. , plus other functions and various custom tools designed for fluid flow, structures and other types of analysis. The modeling began by creating a base for the making of one of the blades of the wind tower, starting from the geometry of a rectangular trapezoid whose dimensions fit the length of the same. Therefore, a third dimension was added to this plane geometry, resulting in a surface capable of enveloping the wind turbine blade. Once this solid was obtained as a base, it was transformed according to the geometry of the blade, chamfering the edges of the surface, cutting them in a bevel, developing the profile of the blades of the turbine's propeller. Once completed, the modeling was continued, drawing up a cylinder from the drawing of a circle at the base of this surface, creating and, therefore, detailing the joint that joins the wind turbine rotor to the wind turbine blade, as shown in Figure 1. Once the modeling of one of the blades was finished, it was continued by copying it to obtain three identical blades arranged at 120º to each other. A parameter was also determined for the rotation of the blades within the axis itself, thus making it possible to analyze the aerodynamic behavior of the structure according to any inclination chosen for the blades, as shown in Figure 2. Once this was done, we started to model the rotor, generated from a cylinder connected to the blades joints, once this was done, the bevel of one of the cylinder bases was made again, producing the rotor tip, as shown in Figure 3. From the extension of the cylinder used in the base of the rotor, the nacelle, a rigid element of the structure, was modeled. Attached to the nacelle, the tower was modeled, formed from the extrusion of an ellipse that gradually widens to the base, which in turn is connected to the turbine foundation, as shown in Figure 4.

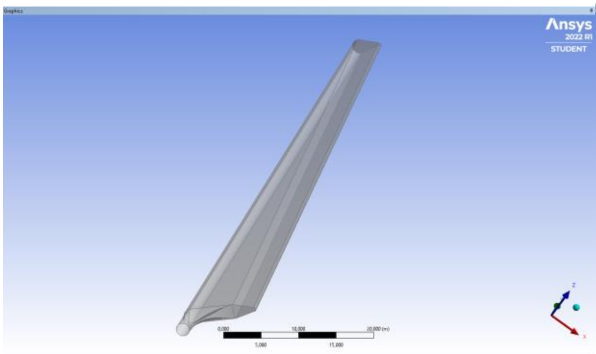

Figure 1. Wind turbine blade modeling.

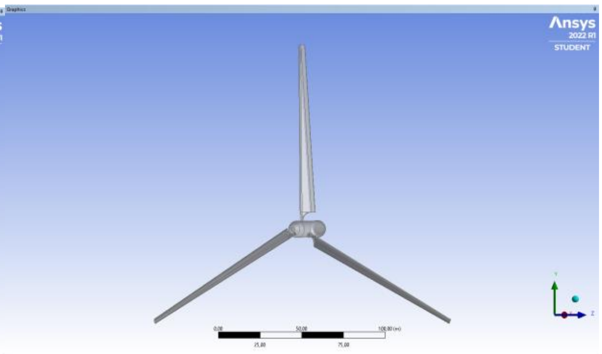

Figure 2. Wind turbine propeller modeling.

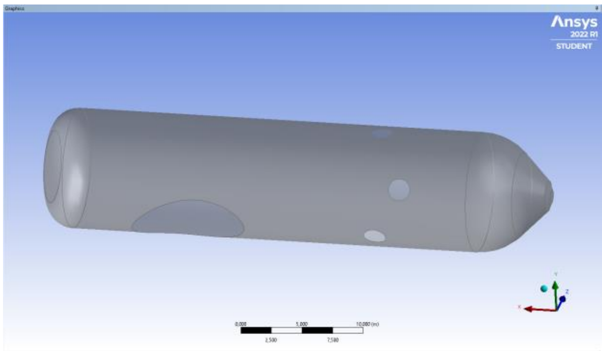

Figure 3. Wind turbine rotor modeling.

Figure 4. Wind turbine modeling.

After the modeling was completed, the software was configured to simulate the action of the winds on the structure. For this, a wind tunnel was created involving the wind turbine, as shown in Figure 5.

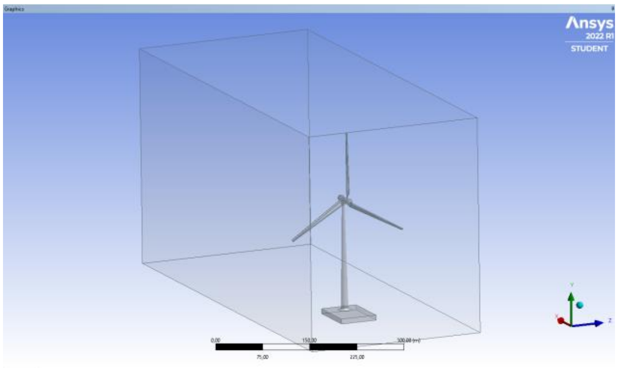

Figure 5. Wind Tunel.

Then, the configuration of the direction of entry and exit of the wind in the structure was carried out; for this, a mesh was made inside the faces of the tunnel, using boundary conditions, the frontal part was delimited as the wind access way, the type of turbulence of the fluid model was defined as RNG k-epsilon and adopted a wind speed of 35 m/s is assumed. Once the definition of parameters and all necessary boundary conditions was concluded, it was possible to start the simulation. The results obtained are presented below.

3 Results

Once the simulation was completed, as results, the pressures in the structure were obtained, the pressure coefficients (cpe) and the wind speed passing through the wind turbine were determined.

For the pressures, in order to better use the performance of the computer used for the simulations, it was decided to prioritize the analysis of the nacelle and blades structure, therefore, the mesh coverage was limited, resulting in a reduction of the studied model. As shown in Figure 6, pressure values that act on the structure are presented.

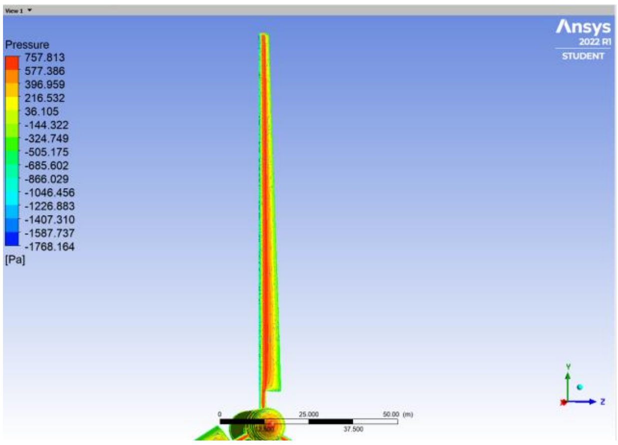

Figure 6. Simulation results – Pressure.

It is possible to observe that the pressures reach a greater intensity precisely in the parts of the structure that have greater contact area as well as the parts of the tower that are perpendicular to the wind direction, such as the rotor tip and the blades faces, as shown. in figure 7:

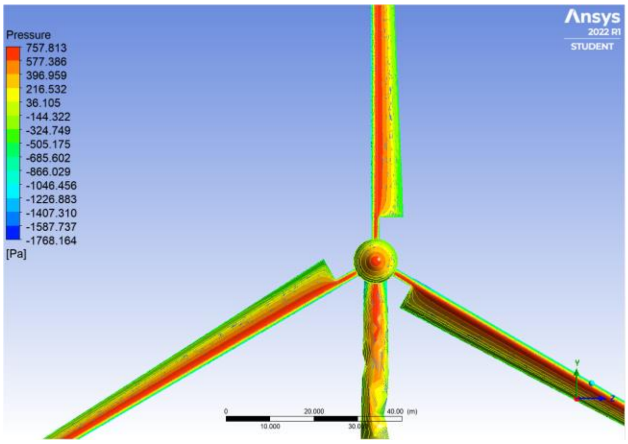

Figure 7. Intensity of pressure on the structure.

To obtain the cpe values, first, in the contour detailing section of ANSYS, one must define the expression for these coefficients, given by:

$$cpe = \frac{pressure}{q} \quad (1)$$

where cpe is the pressure coefficient in the structure given by the difference between the external pressure and the adopted gage pressure, obtained with the simulation, divided by the dynamic pressure of the fluid. This dynamic pressure was obtained by the product of the air density and the wind speed squared, divided by two, that is:

$$q = \frac{1}{2} * \rho * u^2 \quad (2)$$

With a dynamic pressure of approximately 725.8 Pa, it was possible to determine the cpe values, as shown in Figure 8:

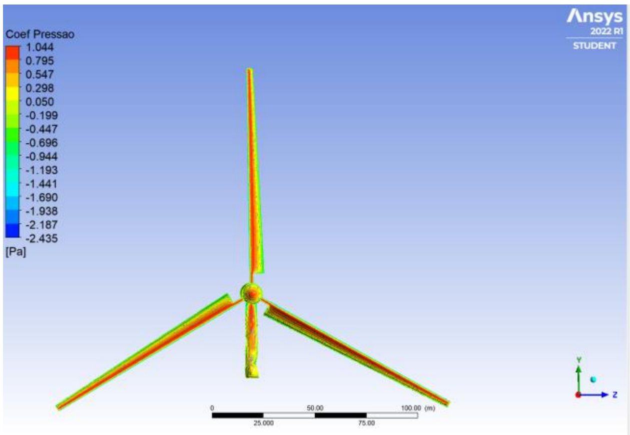

Figure 8. Simulation Results - Pressure Coefficient.

Finally, positioning a YZ plane on the model, and applying a pressure contour acting on it, it was possible to obtain the wind flow velocity and the streamlines acting on the structure, as shown in Figure 9:

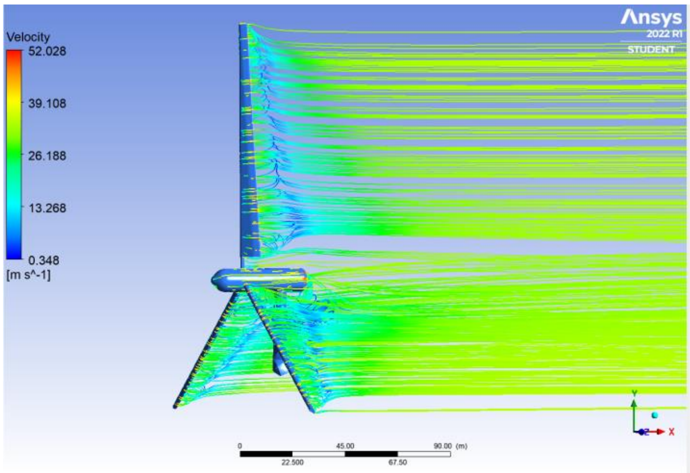

Figure 9. Simulation results - Current line behavior.

Additionally, through the streamlines, it is possible to observe the formation of the vortex on the wind turbine rotor blades, as shown in Figure 10:

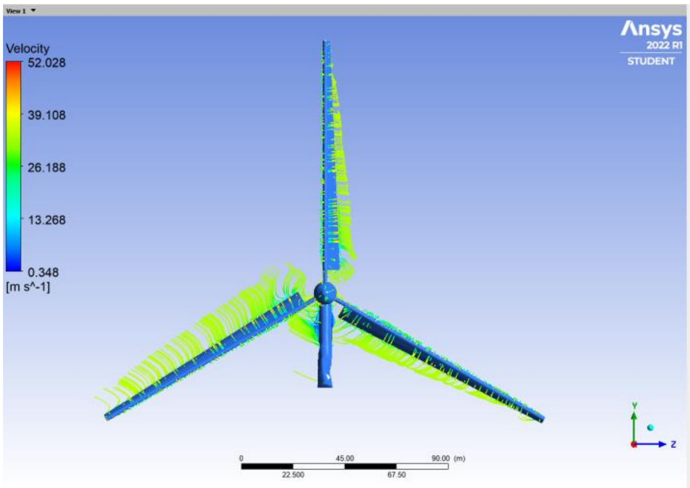

Figure 10. Simulation Results - Vortex Formation.

4 Conclusions

In recent years there has been a growing demand for alternative energy sources, including wind, which new technologies have been improving and optimizing its efficiency. Knowing the physical effects that influence the generation of wind energy is essential for the development of turbines, the more research is carried out in the area, the greater the approximation between theoretical design and the results obtained during the tower's operation. The developed modeling had some limitations, mainly referring to the performance of the computer used, which resulted in the reduction of the studied model. However, it was observed that the parts with the largest area of contact with the wind and the areas perpendicular to it, suffer the largest pressures. Wind turbines have the characteristic of varying their natural frequencies and vibration modes according to the rotation speed of the blades, so these more exposed areas are more susceptible to the actions of aerodynamic phenomena, especially vibration (Flutter) that influence the performance of the wind tower and, consequently, in it's energy production.

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