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ASSESSMENT OF THE NOISE LEVEL DELIVERED BY THE LENZ – VERTICAL AXIS WIND TURBINE BY USING CFD TECHNIQUES

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Abstract: The need for renewable energy sources has become more and more pronounced in recent years, both because of the high level of pollution and because of the limited resource of fossil fuels. Dwindling oil resources combined with environmental concerns have led to a focus on renewable energy, which should be inexhaustible and pollutant–free. Wind energy has proven to be a viable solution for the energy independence of EU member states. However, the problem related to the noise pollution, that a wind turbine can have in operation, persists. The present work is based on the numerical analysis of the aerodynamic noise produced in operation by a vertical axis wind turbine, Lenz type. The turbine was tested at a wind speed of 12m/s using the commercial CFD software Ansys Fluent. To determine the noise level, the turbine blades were set as noise sources and the receivers were placed 6m respectively 12m from the center of the wind turbine which is installed in a 6m high. The results include the noise distribution for the two receivers, but also the distribution of pressures, streamlines and vorticity magnitude contours.
Keywords: Wind turbine, Lenz, CFD, noise

1. INTRODUCTION

According to the latest European regulations [1], it is proposed to bring renewable energies to a share of up to 32% of the total energy produced by the year 2030. This threshold can be exceeded with the help of wind energy, by developing new production systems and energy storages. Romania's wind potential is estimated at 14,000 MW – currently installed power [2], which corresponds to 23,000 GWh of electricity annually. diana_manoleli@yahoo.com

Research in the field of renewable energy produced with the help of wind sources has experienced a significant increase in Romania [3, 4]. In 2010, Romania ranked 7th in the EU in terms of installed capacity in wind energy, and in 2012, the renewable energy produced by the more than 1000 wind turbines represented 3% of the total energy.

Representative works in the field of wind turbines belong to I. Paraschivoiu [5,6], who studied the efficiency of wind turbines using numerical methods. Numerous factors, such as the number of blades, the profile chord and the wind speed [7] influence the performance of the wind turbine. To estimate their interactions, CFD methods are intensively used [8]. They are derived from leading fields such as aerospace engineering or the nuclear industry and are based on the finite volume method that uses the spatial discretization of a computational domain in volume elements (hexa/tetrahedral). Structured grids are used for high–precision simulations.

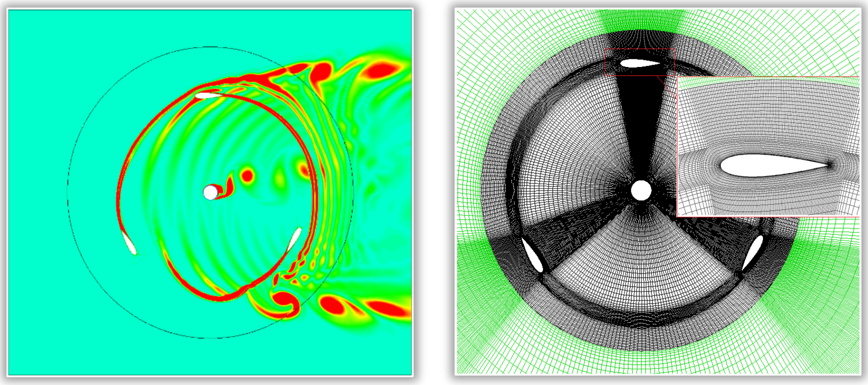

Figure 1 – Vorticity at the vertical axis turbine (left) and the discretized domain (right) [9]

Among the advantages of using these methods is the ability to study phenomena for which experiments would be very expensive if not impossible. In addition, the interactions in a complex physical phenomenon can be studied simultaneously without imposing certain assumptions.

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Wind is the movement of air from an area of high pressure to an area of low pressure, this movement being caused by the uneven heating of the earth by the sun. That is why the energy produced with the help of the wind is also called indirect solar energy [10]. The strength of the wind varies with altitude, this is due to the friction between the moving air and the Earth's surface. The end of oil resources combined with ecological reasons (related to pollution) led to the focus on the production of energy from renewable energies which are practically considered inexhaustible and with zero pollution [11].

To capture wind energy, wind turbines (wind turbines) are used, which convert kinetic energy from the atmosphere, either into mechanical energy or into electrical energy.

A first classification of these machines can be made according to the aerodynamic forces. Thus, there are turbines that work on lift or on drag. The most efficient ones are the lift ones, as they manage to convert wind energy best.

Turbines can also be classified according to the axis of rotation: horizontal turbine (HAWT) and vertical turbine (VAWT). The most common is the horizontal one which is of the "propeller" type (HAWT). For perfect operation, the horizontal axis turbine must be oriented in the direction of the wind, while the vertical axis turbine does not take the wind direction into account.

VAWT offers a number of advantages over traditional horizontal axis wind turbines (HAWT) it starts at lower wind speeds and does not take into account its direction and turbulence, they are omnidirectional and do not need to follow the wind, being thus more efficient in areas with wind turbulence. This means that it does not require a complex mechanism and motors to turn the rotor and change the blades.

In the specialized literature there is a theory for estimating the power generated by a wind turbine [12].

$$P_{vânt} = \frac{1}{2}\rho S V_\infty^3 C_p \tag{1}$$

where Cp – represents the power coefficient, which in the ideal case is 1 (wind power).

However, according to Betz's theory [13], the power coefficient cannot exceed the value of 0.593.

$$C_{pT} = \frac{P_T}{P_{vânt}} = \frac{M \cdot \omega}{\frac{1}{2}\rho S V_\infty^3} = \frac{\frac{1}{2}\rho S V_\infty^2 L C_m \omega}{\frac{1}{2}\rho S V_\infty^3} = C_m \cdot \frac{L\omega}{V_\infty} = C_m \cdot \lambda < 0.593 \cong \frac{16}{27} \tag{2}$$

The maximum power that can be extracted from a wind turbine can be estimated with the help of Betz (Betz's Law). According to what Betz said, the wind turbine cannot extract more than 16/27 (Betz's Coefficient – 0.593) of the wind's kinetic energy.

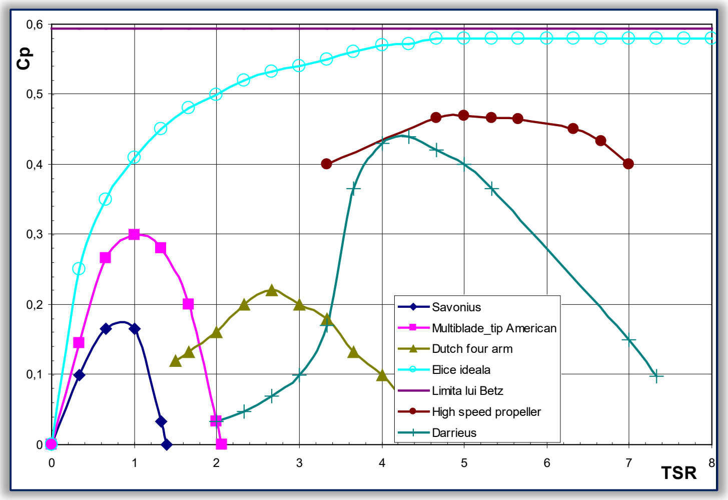

Figure 3 – Power coefficient variation depending on TSR for different types of wind turbines [14]

However, considering all the above, the energy produced by the wind, which presents numerous advantages, from the fact that it is "friendly" with the environment, i.e. it presents zero pollution, to the development of technology for these machines that manage to capture this energy, is starting to be quite a promising alternative for the future.

Returning to vertical axis turbines type, in this paper an analysis of the noise level produced by the vertical axis wind turbine that operates at a wind speed of 12m/s (43.2km/h) and is located at a height of 6m was monitored and has a maximum installed power of 5kW were done.

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A commercial CFD–ANSYS–Fluent code [15] was used for the simulation. The discretization scheme used is a 2nd order upwind type, and the turbulence model used is k–ω SST. This model is a two–equation model and combines two standard turbulence models, k–ε and k–ω.

This study was done on the 3D case of a Lenz type vertical axis wind turbine. The geometry of such a turbine is shown in figure 4.

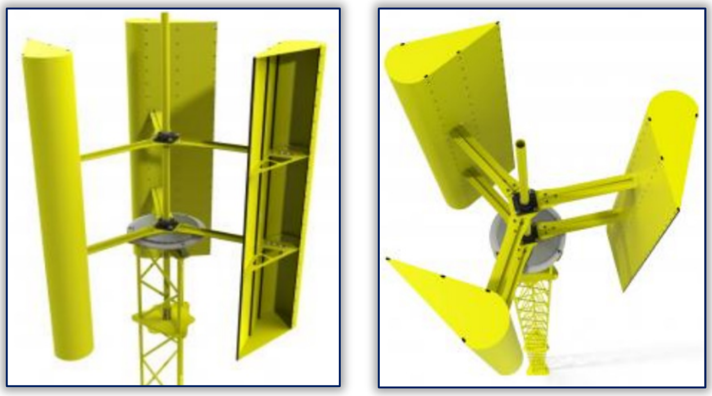

Figure 4 – Geometry of a vertical axis wind turbine

2. PAPER CONTENTS

The computational domain is made up of two parts, one stator and the other is represented by the rotor. At the intersection of the two subdomains, an interface is declared that helps transfer information between the rotating domain represented by the blades, the axis together with the support rods, and the static domain represented by the surrounding environment.

Figure 5 shows the two domains, the rotating domain and the stator domain used in the numerical analysis carried out with the help of CFD methods. The vertical axis wind turbine radius was imposed. The entry into the stator domain was placed at ten radii where a constant wind speed value of 12m/s was imposed.

Table 1. – Case settings in the ANSYS–Fluent solver

Models	Solver	Pressure Based	Unsteady	3d
	Viscous Model	k–ω SST		
Materials	Air	Density, I note		
Operation conditions	Pressure: 101325[Pa]			
Boundary Condition	entry	Velocity inlet: V_x=12m/s (43.2km/h)		
	blades	Walla		
	shaft	Walla		
	Interface	Rotor–stator interface		
	Rotor	Mesh motion		
	Stator	Stationary		
Solve	Controls	solvable	Current no=2	Discretization 2nd order upwind
	Initialize	entry		
	Monitors	Residuals	10^{-6}	
		Forces	Momentum quotient	
	iterated	10^{6} Steps	0.001s time step size	
carry	Reference values	entry	Length=radius of the turbine	

To generate the mesh, the blocking method was used in the software for generating the computational domain – ICEM CFD.

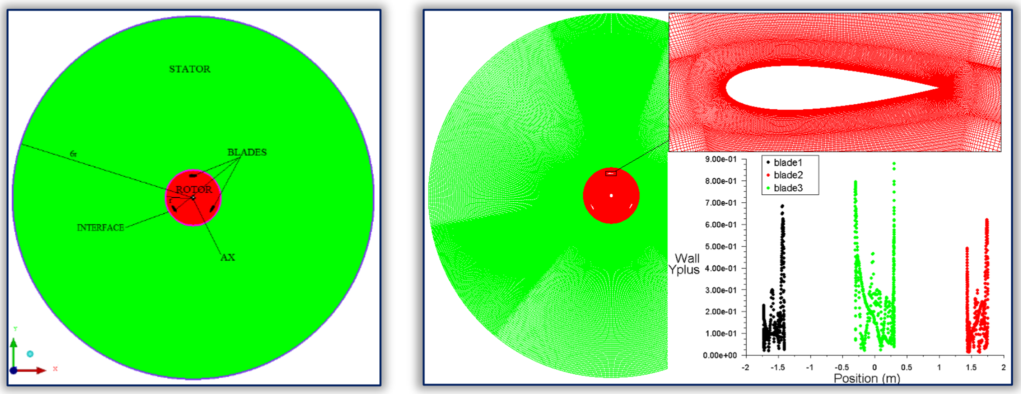

Figure 5 – Section through the computation domain with y+ for all blades

In order to solve the problems that may appear in the boundary layer area, when generating the calculation grid, it was taken into account that the value of Y+ should not be greater than 1, and the growth ratio of the elements should not exceed 1.1.

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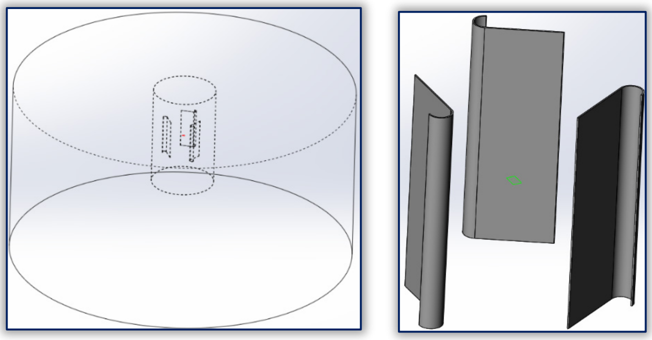

Figure 6 – The 3D domain together with the three blades of the wind turbine with a vertical axis

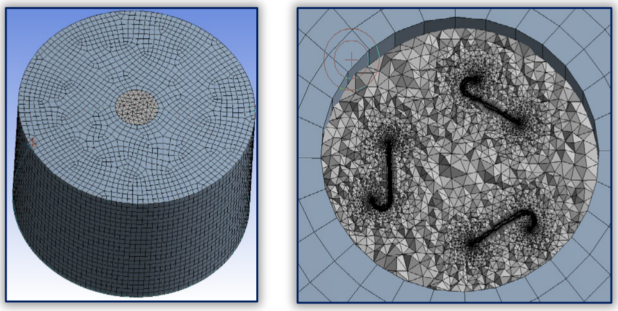

Figure 7 – The mesh

The detailed formulation of a turbulence model can be found in the works of Menter et al. [16] and Langtry et al. The SST Transition turbulence model was stated by Menter and is a four–equation model. Two more equations are added to the standard equations of the k–ω SST model designed to solve the problems that appear in the transition zone between the laminar and the turbulent zone. And for the noise analysis we used the Ffowcs Williams and Hawkings acoustics model [17]. In the numerical determination of the noise, the turbine blades that produce an aerodynamic noise in operation were defined as sources and the receivers were established at 6m and 12m from the center of the turbine.

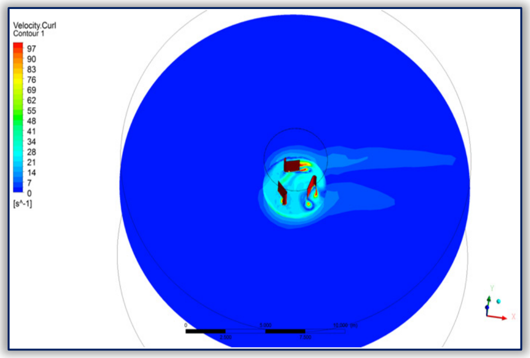

Figure 8 – Vorticity magnitude

The results obtained from the numerical analysis are based on the variation of vorticity and pressure both on the turbine blades and in the surrounding area. The below figures show variations of vorticity, pressure, and the structure of the flow lines that dictate flow around the wind turbine.

Regarding the analysis of the noise produced in operation, figures 11 and 12 show the variation of the noise pressure for the two receivers placed at 6m and 12m.

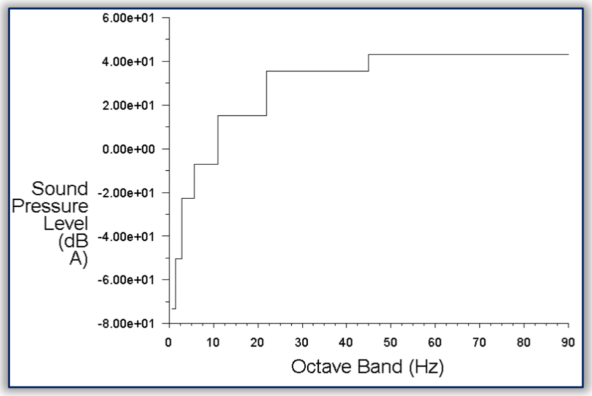

Figure 11 – Noise level distribution for the first receiver from 6 m

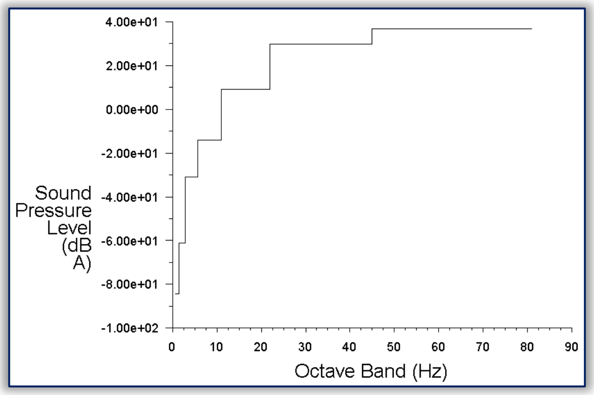

Figure 12. – Noise level distribution for the second receiver from 12 m

Thus, the noise level was determined for receiver number one and has a value of 43 dB and for receiver two a value of 36 dB. According to the aircraft noise determination site [18], this noise can be associated with the noise in a living room

The noise produced by the wind (ambient acoustics), by the friction of air particles (gusts of wind) against buildings or trees, is also of particular importance in the general evaluation when it is desired to establish all the factors that produce noise in the ambient environment. According to the measurements made by the Ministry of the Environment and Climate Change [19] from Canada (April 2017), the noise level produced by the movement of the wind at the level of 10ms is approximately 51dB, i.e. much higher than the level of the turbine studied by us.

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3. CONCLUSIONS

In this work, the noise level produced by the Lenz type vertical axis wind turbine was analyzed. This turbine has a diameter of 2m, a blade height of 2.5m and is installed on a 6m pole. The turbine was analyzed at a wind speed of 12m/s using CFD methods. ICEM CFD software was used to create the mesh and Ansys Fluent software was used to solve the system of equations defining the flow around the wind turbine.

The final conclusion consists in the fact that the studied turbine lends itself, from an acoustic point of view, to use in urban or rural environments, the noise level produced by it being below the legal limits (according to WHO 536, the external noise level is measured 3 m from the external wall of dwelling and must be less than or equal to 50dB for the day and 40dB for the night).

Nomenclature

P_{wind} – wind power [kW];
P_T – turbine power [kW];
CpT – turbine power coefficient [–];
M – torque [Nm];
Cm – torque coefficient [–];
ω – rotation speed [rad/s];
ρ – air density [kg/m^3];
S – reference surface [m^2];
V_∞ – wind speed [m/s];
λ – TSR tip speed ratio [–].

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