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CFD Analysis of a Wind Turbine Assembly Model

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Abstract: *The need for energy is growing worldwide today and hydrocarbon reserves are limited resources that are exploited at full capacity at this moment. Also noxious products released into the atmosphere due to the burning of hydrocarbons have harmful effects on the environment. Therefore the research activities and development of solutions for obtaining energy from renewable sources are fully supported in most countries with a high level of economic development. Such solutions are including the solar power, wave energy or wind force. Wind force generated by the movement of air masses between areas with pressure differential is an inexhaustible resource that can easily be converted into electricity in an environmentally friendly manner without the need of fuels combustion. To harness the energy produced by the movement of air currents many wind farms were developed, composed of many wind turbines that by rotational movement are generating electricity. Around the world there are areas where wind is acting with a constant velocity in time being considered as ideal locations of installing wind turbines through which wind power is converted into electricity. In this paper is described a wind turbine assembly for which was conducted a three-dimensional model with Solid Edge V20 CAD program. A CFD analysis was carried out for the wind turbine model using ANSYS CFX in order to highlight the working process of the turbine when describing the rotational movement of the propeller within the fluid region represented by air which is describing a translational movement with imposed velocity.*

Keywords*: wind turbine, 3D modelling, computational fluid dynamics (CFD)*

1. Introduction

The increase of energy needs at present is inevitable on the background of continuous growth of the number of inhabitants and their living standards. As alternatives to conventional energy production processes are methods based on capturing solar energy, wind or wave power. All these methods are considered as environmentally friendly processes that have a huge potential for exploitation, which is currently insufficiently exploited.
Among the methods presented the process of obtaining energy using wind power is one with great potential for development worldwide. From the earliest times of antiquity they were used applications that were based on wind power and in the Middle Ages many windmills were built. Nowadays modern wind turbines are built on continental areas with constant strong winds as well as on the sea, near the coast.
The winds, as a result of the dissipation of solar radiation into the atmosphere and the earth rotational motion, are generated due to the movement of atmospheric air masses due to activity of the sun that heats unevenly the ground. Due to this fact air masses are found having different temperatures, which leads to the movements occurrences.
The warm air being lighter and with lower pressure tends towards for ascending movement, while cold air is denser, weighty and having a greater pressure. Such an imbalance is created that generates thermal and baric air movement in areas with higher pressure to lower pressure areas tending towards the achievement of uniformity value of pressure at equilibrium. Thereby the winds arise, that as a result of the earth rotation and the occurrence of inertial forces have trajectories that change in different ways, proportional to the height at which they are located above the ground.
The air movement at high velocity and approximately constant over time is capable of forming significant pressure forces on propeller blades surface of a wind turbine which determine its rotational movement.

Calculations were carried out whose result shows that about 25% of solar energy that reaches the earth's atmosphere is converted into wind energy which is a huge source of energy for mankind. The total wind energy that is available and can be taken at this time exceeds more than 4 times the energy needs of humanity.
The share of energy production based on wind force has increased by approximately five times between 1999 and 2006 reaching, in some countries, the share of wind energy in total energy consumption to be quite important. For example for European countries bordering the sea or ocean the wind energy share of total energy production is approximately 23% in Denmark, 8% in Spain and 6% in Germany.

2. Wind turbine assembly model

The wind energy can be captured using special construction plants, equipped with turbine, capable to take over wind force and convert it into mechanical energy (direct mechanical work) or electricity through a generator.
A three-dimensional model for a wind turbine assembly was made using Solid Edge software in a simplified manner which is presented in 0.

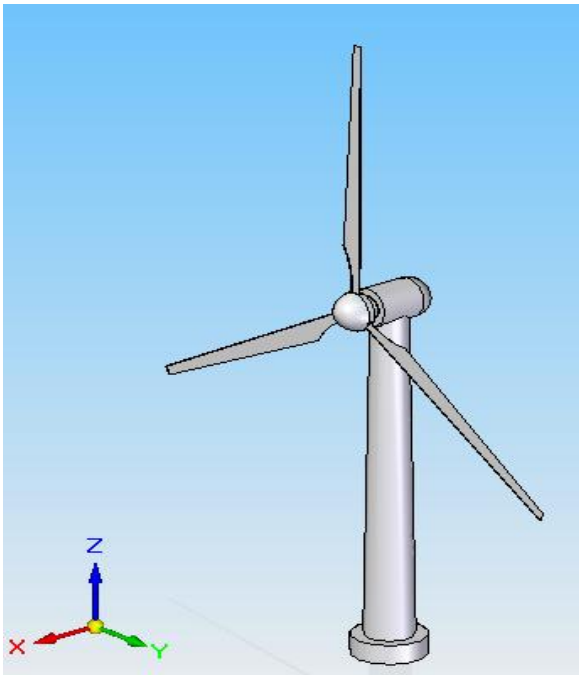


Fig. 1. Wind turbine three-dimensional model assembly

The turbine assembly performs the process of converting wind energy into mechanical energy through the interaction forces between the airflow and blade surface. The blades are constructed with an aerodynamic profile and are usually made of fibreglass or polymeric material. In order to achieve an efficient capture process the turbine has to be oriented so that the plane of blades rotation to be oriented perpendicular to the wind direction. The heights of a wind tower have different values (60 to 130 m) and the total height at which wind turbines have been constructed was up to 200 m. [7]
The wind brings the amount of kinetic energy which is converted into mechanical energy through the turbine. Wind energy is considered as transiting air energy through an area at a given moment of time. The wind power can be evaluated by the relationship: [6]

$$P_w = \frac{1}{2}\rho_a A_p v_w^3 \tag{1}$$

Where:
- P_w - wind power;
- ρ_a - air density;
- A_p - propeller covered surface;
- v_w - air velocity.

Under normal conditions of pressure and temperature can not be captured the total power amount due to the friction forces that prevent the air exhaust that already performed the mechanical work on the turbine blades. It is necessary to introduce an adjustment coefficient value to be used in the power calculation relationship that describes the turbine total power efficiency. Thus the equation that describes the wind turbine real power amount can be evaluated as: [6]

$$P_{wt} = \frac{1}{2} c_p \rho_a A_p v_w^3 \tag{2}$$

The adjustment coefficient of power provided by the wind turbine, (c_p), is expressed as the ratio between the turbine mechanical power of and the total power that can be captured. Based on the analysis of the power factor it was determined that a wind turbine is more energy efficient as the number of blades is lower. A turbine with a smaller number of blades develops a lower resistant moment and finally will have a higher rotational speed. The highest value of efficiency factor is recorded at three-bladed wind turbines.
It was established the theoretical value for the wind turbines power coefficient at approximate value of 55% from total wind energy. In reality the power coefficient of wind turbine models currently used is 30 - 40% of wind energy. [6]
Currently, there are several types of wind turbines made with different models and values for the propeller blades, coverage area and tower heights. In Table 1 are presented some calculation values for the turbine diameter, area covered and mechanical power at the turbine shaft depending on the wind velocity.

TABLE 1: Calculation specific parameter values for wind turbine

Wind velocity (m/s)	Turbine diameter (m)	Turbine area (m^2)	Turbine power (kW)
12	5	19.63	6.85
13	15	176.70	78.47
14	25	490.85	272.24
15	35	962.08	656.30
16	45	1590.38	1316.68
17	55	2375.75	2359.22
18	65	3318.20	3911.48
19	75	4417.73	6124.63
20	85	5674.33	9175.39
21	95	7088.00	13267.90
22	105	8658.75	18635.62
23	115	10386.58	25543.26
24	125	12271.48	34288.69
25	135	14313.45	45204.81

They were calculated the appropriate amount values for the mechanical power obtained at the turbine shaft by using the turbine covered area, wind velocity, air density and the adjustment coefficient of 33%.
A diagram is shown in Figure 2 in order to emphasize the numerical results for the total power at the turbine shaft function of the turbine blades covered area during the rotation movement.
In the calculation the wind velocity was considered within the range of *12-25 m/s* and the air density of $1.225\,kg/m^3$ at temperature of $15^{\circ}C$.

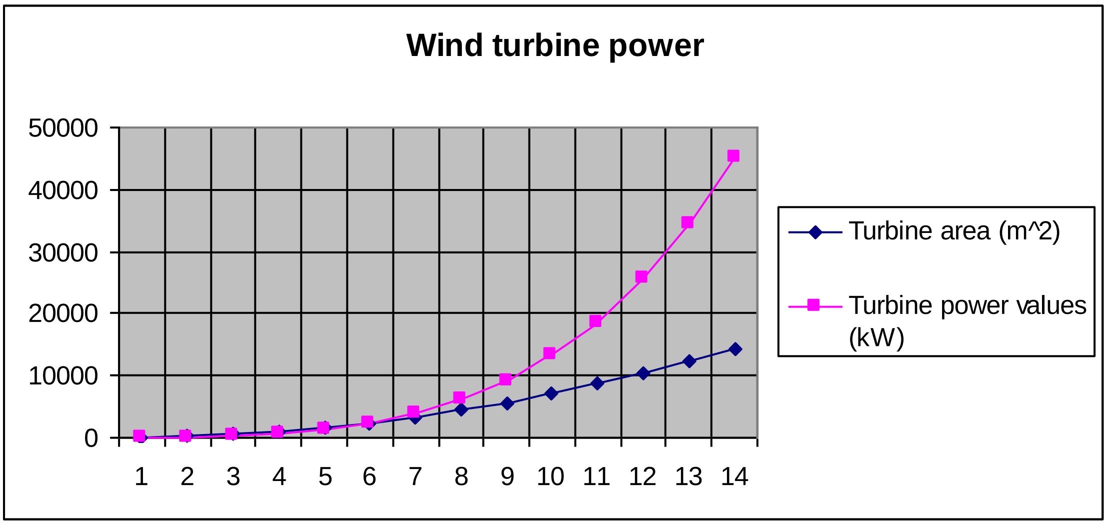


Fig. 2. Wind turbine power for different covered area values

The calculated values for the mechanical power at the turbine shaft depending on wind velocity values acting on the turbine propeller blades are shown in Figure 3. The wind speed is the key parameter in the operation of wind turbines but the optimum operation relies on wind constant action over time. At very high wind velocities can be compromised the integrity of the turbine and in this situation by using special braking devices the turbine can be slow down ensuring in this way a safe operation during strong wind conditions.

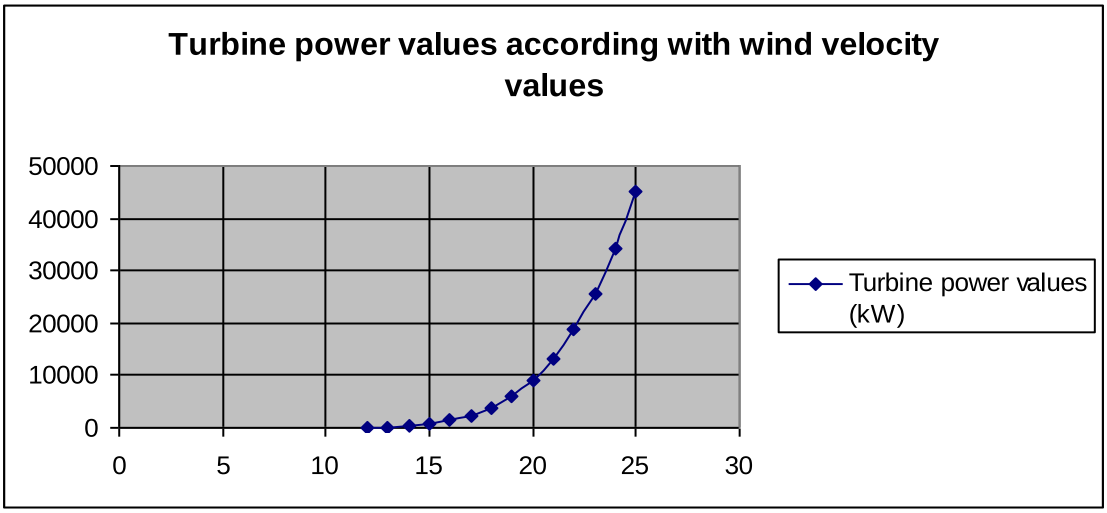


Fig. 3. Wind turbine power for different wind velocity values

3. Computation fluid dynamics analysis for the wind turbine assembly model

In order to achieve a numerical analysis using ANSYS CFX software the three-dimensional model of the wind turbine has been imported into Design Modeler where it was declared the fluid region as a turbine enclosure, as shown in Fig. 4.

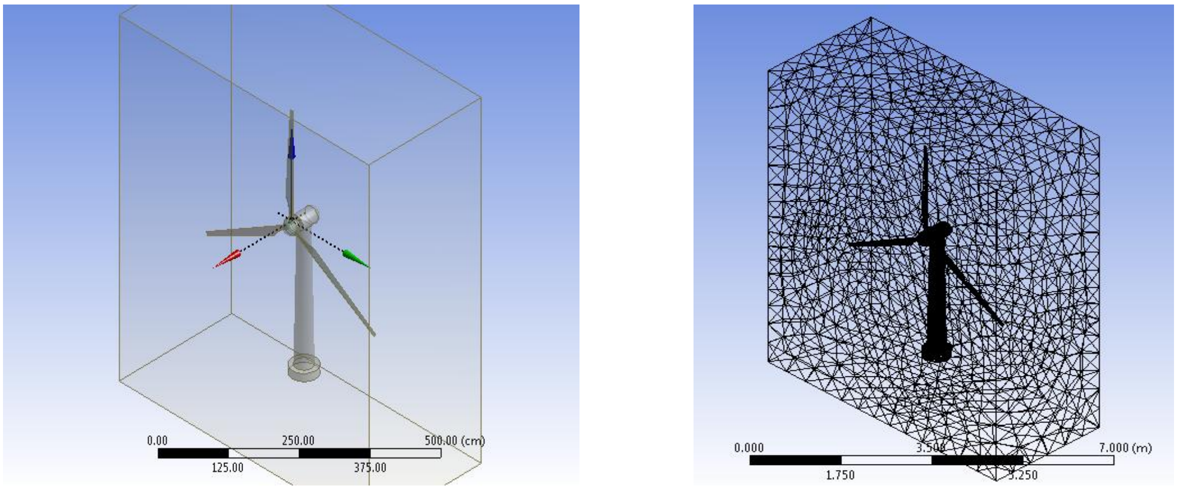
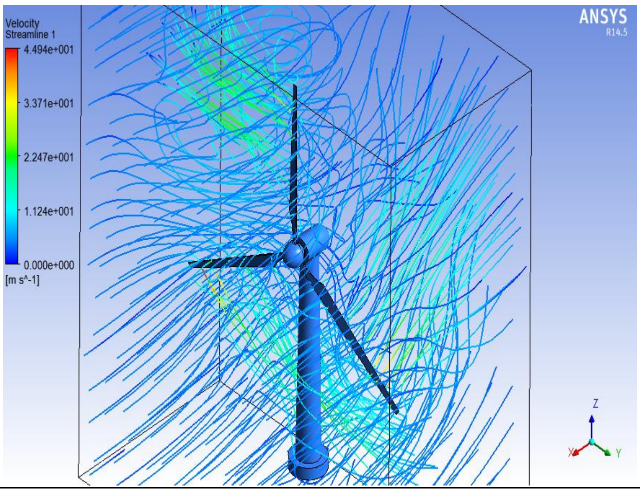
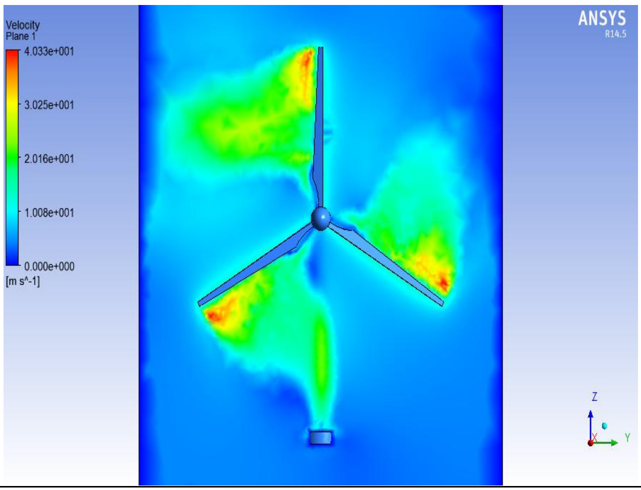
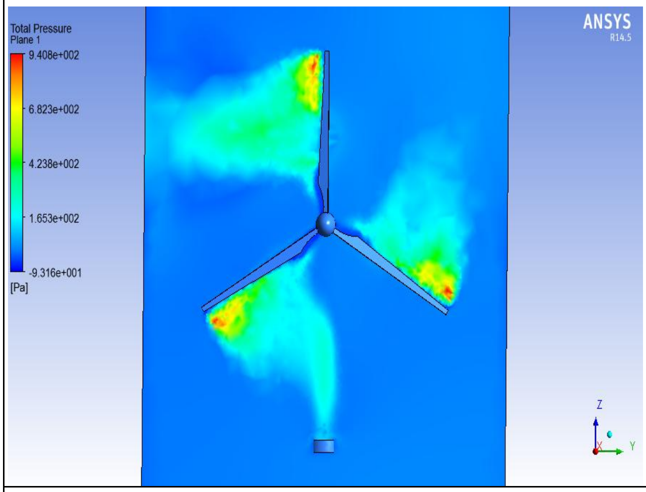


Fig. 4. The wind turbine assembly model imported in ANSYS Design Modeler and Mesh

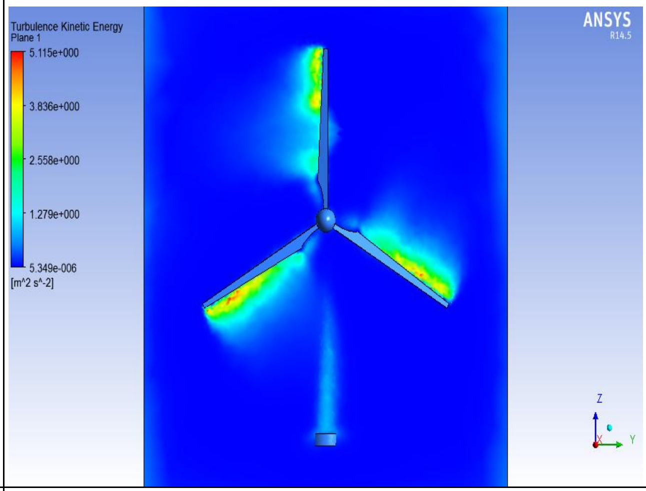
It was then performed finite element mesh network of triangular shape with a number of 55453 nodes and 301293 elements using CFX Mesh. Defining the proper analysis was performed with CFX Setup, where they were declared initial data necessary for starting the calculation process. After the calculation they were achieved results regarding the working fluid flow (air) inside the analyzed fluid region and how the turbine rotational movement occurs within the fluid region creating specific turbulences. The results are presented in terms of air velocity and pressure in the turbine propeller blades plane.
The values obtained for the fluid velocity and total pressure for the analyzed case are presented in 0.

TABLE 2: Result values obtained for total pressure and fluid velocity

	
a) Velocity streamlines	b) Velocity values in YZ plane



c) Pressure values on YZ plane



d) Turbulence kinetic energy values on YZ plane

4. Conclusions

A wind turbine model was built and analyzed in terms of the operating principle in this paper. The computational fluid dynamics (CFD) analysis was performed using ANSYS CFX and the results are presented in terms of velocity and pressure of the working fluid represented by air. It was calculated the mechanical power at the turbine shaft depending on the area covered by the propeller blades taking into consideration the wind velocity values acting directly on the turbine.
The wind power is an inexhaustible resource of energy that can be captured easily using wind turbines. It is a viable alternative to burning fossil fuels for electricity and is getting used increasingly more in favorable areas where the winds act with a constant force in time.
Currently, there are regions with entire parks of installed wind turbines generating electricity in an environmentally friendly manner and energy production per turbine is around of 1.5 - 7.5 MW. These wind plants have considerable dimensions with overall height range of 100 to 200 m, with a rotational velocity ranging between 10 to 20 rev / min and working safely at wind speeds between 12 and 15 m / s. [7]

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