Green Energy from Wind Action

Assistant professor **Fănel Dorel ȘCHEAUA[1],** Prof. PhD Eng. **Ion DAVID[2]**

[1] "Dunărea de Jos" University of Galați, fanel.scheaua@ugal.ro

[2] Technical University of Civil Engineering of Bucharest

Abstract: *The atmospheric air front movements determine the winds occurrence. Due to the continuous action of the sun on the atmospheric air masses exposed successively as a result of the earth's rotational motion, different values of the air temperature are obtained, which correlate with the atmospheric pressure values, are forming air masses zonal movements. Over time, special constructive units have been developed that can take the air motion energy in order to achieve continuous rotational motion at a turbine shaft. At present, the wind force ensures a significant amount of necessary energy production for human communities but far from using the whole winds potential worldwide. The constructive and operational characteristics of the wind turbines provide a solution of obtaining green energy with reduced environmental damage. Aspects presented in this paper are related to fluid mechanics elements describing the air motion at the wind turbine blades level that is capable to determine the shaft rotational motion. Also, an air flow analysis is performed on a virtual model of a wind turbine propeller in order to highlight the flow regime according to specific values of the air circulation velocity.*

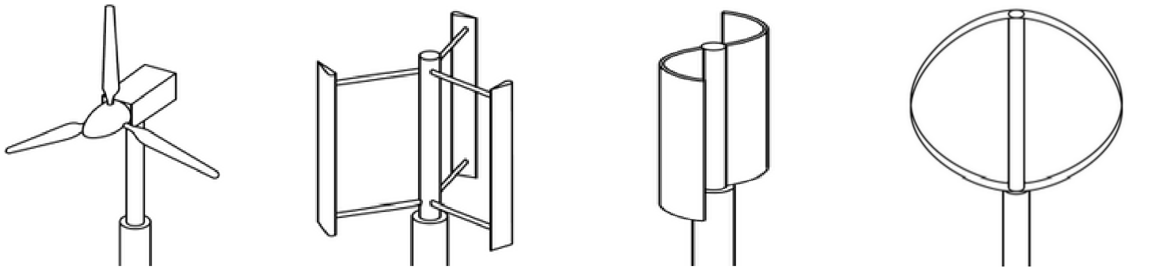
Keywords: *Air flow, energy recovery, three-dimensional modelling, CFD*

1. Introduction

Every human activity was made in order to satisfy community needs over the times so that every possible resource was taken into account so far. For energy needs traditional fuels have been used during a long period but in time this solution became unfriendly with the environment. So another solutions had to be developed in order to obtain energy from wind action, wave action, water falls or sun power. In this paper is presented a solution of wind power plant from the operational point of view and a model of horizontal axis turbine which use the wind action in order to acquire the axial shaft rotation, necessary for energy production.
The energy produced on the basis of air currents has great potential and represents a sustainable production method by means of which the energy conversion that takes place at the level of the wind power plant rotor. The major advantage that result from the use of wind power plants is related to the carbon dioxide amount that is avoided to be discharged into the atmosphere due to the energy production by using the traditional burning fossil fuels production methods. Even if only 2.5% of the total energy consumed globally is now produced by the wind action, there must be considered the development and increase of the wind energy production amounts ensuring in this way a cleaner environment for the future.

2. Wind turbine operational aspects

The general aspects that characterize the movement of the atmospheric air and the possibilities of capturing and converting the energy within the constructive units of electricity generation used at the present time worldwide are presented.
Depending on the size of the turbine rotor, optimal results regarding the energy values produced in the wind power stations are obtained.
A classification of the wind turbines can be made from the position of the rotor axis. This includes turbines with horizontal and vertical axis. Horizontal axis turbines have the peculiarity of taking the air stream lines from the wind in a direction parallel to the rotor axis, while the turbines with the vertical axis take the air flow path lines in a direction perpendicular to the rotational axis.
Most commonly used with higher installed power are the horizontal axis turbines for power generation worldwide, while vertical axis turbines are used less with much lower installed power.



a) horizontal axis turbine b) Darrieus H vertical axis c) Savonius vertical axis d) Darrieus vertical axis

Fig. 1. Principal wind turbine constructive types [8]

The operating performance of a wind turbine is related to the wind velocity values and its direction. Wind turbines have great operating efficiency when there is optimum airflow velocity and must be positioned to be able to receive directly and take over the power from the optimum wind direction.
In order to install a wind turbine, it is important to establish the economic conditions of energy production related to the duration of action and the wind velocity within a respective region, which describes the wind resources present per year.
The wind power density value expressed in power units per unit area $\left(W/m^2\right)$ is described. This parameter comprises the combined effects of the frequency distribution of the wind velocity together with the dependence on the air properties related to density.
The total power value of the wind acting on the surface of the turbine rotor is described by the relation: [1]

$$\frac{dm_a}{dt} = \rho S v \tag{1}$$

$$P_T = \frac{1}{2}\frac{dm_a}{dt}v^2 = \frac{1}{2}\rho S v^3 \tag{2}$$

where: S -rotor surface area, v -wind velocity, ρ -air density.
The average value of the power density of the air circulation over the surface unit can be described as follows: [1]

$$\frac{P_T}{S} = \frac{1}{2}\rho v^3 \tag{3}$$

It is obvious that the wind power density values are proportional to air density, turbine rotor diameter and the cube of air velocity.
The power potential produced by a wind turbine is based on the laws of fluid mechanics that describe the air circulation through the turbine impeller and the aerodynamic characteristics of the rotor.
Some values of available power per surface unit are presented in table 1 according with wind velocity.

Table 1: Values for available power function on wind velocity

Wind velocity *(m/s)*	**Available power/area unit** $\left(W/m^2\right)$
5	80
10	610
15	2070
20	4900
25	9560
30	16550

For some regions the wind velocity values during the year are measurable and known so that the wind turbines positioning can be established in order to obtain optimal results characterized by high efficiency in the energy production. The estimated average values of the available power can thus be determined based on the average hourly velocities available for a whole year:[1]

$$\frac{\bar{P}}{S} = \frac{1}{2}\rho\bar{v}^3 C_E \tag{4}$$

where $\bar{v}$ - represents the average value of wind velocity and C_E is the energy factor coefficient described by the relation: [1]

$$C_E = \frac{1}{n_h \bar{v}^3}\sum_{i=1}^{n_h} v_i^3 \tag{5}$$

Relation that consider the total number of hours (n_h) in a year.

A realistic evaluation regarding the total amount of wind power on surface unit available for a certain region is made: [1]

$$\left(\frac{\bar{P}}{S}\right) < 100\ \frac{W}{m^2}\ - Low\ potential\ values$$

$$\left(\frac{\bar{P}}{S}\right) \cong 400\ \frac{W}{m^2}\ - Good\ potential\ values$$

$$\left(\frac{\bar{P}}{S}\right) > 700\ \frac{W}{m^2}\ - Great\ potential\ values$$

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3. Air circulation velocity and flow rate along rotor blade surface

It is considered the case of air potential movement at the level of a curve delimited by the points A and B positioned on the rotor propeller blade within the air stream.

At each contour point an air stream line passes. A fluid particle has a velocity that passes at some point P and the components *(u)* and *(v)* with respect to the *OXY* coordinate system and (v_n) and (v_t) relative to a system with the origin at point P and the normal and tangential axes at the blade contour curve. [2]

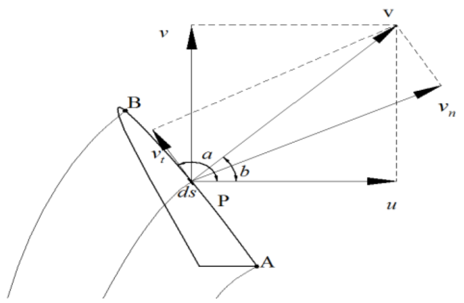


Fig. 2. Schematically representation of air circulation velocity and flow rate [2]

The air velocity circulation along the contour curve AB can be written as follows: [2]

$$\Gamma_{AB} = \int_{AB} v_t ds \tag{6}$$

On the schematically representation of air circulation in figure 2 the following relations are considered: [2]

$$v_t ds = \mathrm{v}\cos(a-b)ds = \mathrm{v}(\cos a\cos b + \sin a\sin b)ds = udx + vdy \tag{7}$$

$$\Gamma_{AB} = \int_{AB} udx + vdy \tag{8}$$

Expressing the two velocity values in another form can be than written the relation for the air velocity circulation: [2]

$$u = \frac{\partial\varphi}{\partial x};\ v = \frac{\partial\varphi}{\partial y} \tag{9}$$

$$\Gamma_{AB} = \int_{AB} \frac{\partial\varphi}{\partial x}dx + \frac{\partial\varphi}{\partial y}dy = \int_{AB} d\varphi = \varphi_B - \varphi_A \tag{10}$$

For the case of a closed curve such as the case of the wind turbine rotor blade, the air flow velocity is equal to the potential increase on the contour curve.
For the values of circulated air flow rates at the contour curve level of the wind turbine rotor blade, can be written the relation for the fluid area between points A and B: [2]

$$Q_{AB} = \int_{AB} v_n ds \tag{11}$$

The following relations can be written from the conditions described by the calculation model presented in figure 1, where the air flow rate equation results: [2]

$$v_n ds = \mathrm{v}\sin(a-b)ds = \mathrm{v}(\sin a\cos b - \sin b\cos a)ds = udy - vdx \tag{12}$$

$$Q_{AB} = \int_{AB} udy - vdx \tag{13}$$

Expressing the two velocity values in another form can be written the relation for the air circulated flow rate in another form: [2]

$$u = \frac{\partial\phi}{\partial y};\ v = -\frac{\partial\phi}{\partial x} \tag{14}$$

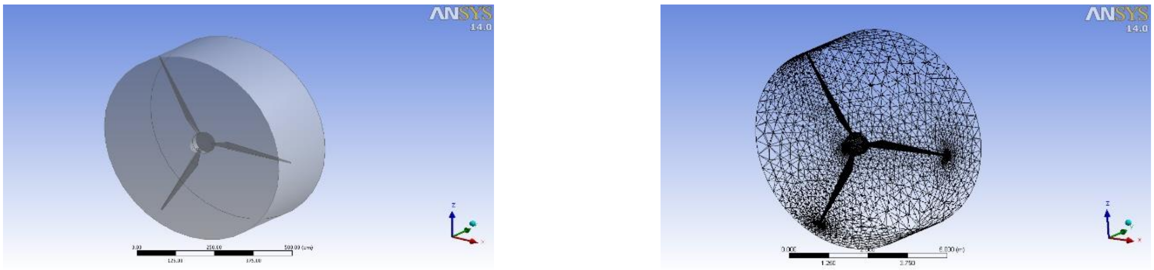
$$Q_{AB} = \int_{AB} \frac{\partial\phi}{\partial x}dx + \frac{\partial\phi}{\partial y}dy = \int_{AB} d\phi = \phi_B - \phi_A \tag{15}$$

The relations obtained for the air velocity circulation and flow rate show that these values are directly dependent on the functions (φ) and (ϕ) calculated at the contour curve extreme points of the wind turbine rotor blade and not depending on the curve shape.

4. Air flow analysis on virtual model

The potential of air mass circulation can ensure the continuous rotational motion of a turbine's rotor shaft so that electricity is generated through the use of a generator.
A three-dimensional rotor model for wind turbine is constructed and analyzed with ANSYS CFX from the air flow point of view in order to highlight the flow pattern and the operational mode based on the air circulation over the rotor blades.
Air velocity values characteristic of regions with relatively constant wind action during the year are adopted, measurable values that are declared as analysis initial values.
The wind velocity range is considered between 3.5-5 m/s corresponding to the hill regions, the plain area and the coastal area where the wind velocities are in higher values.
The adopted value for air velocity is 4 and 5 m/s for the two analysis conducted.

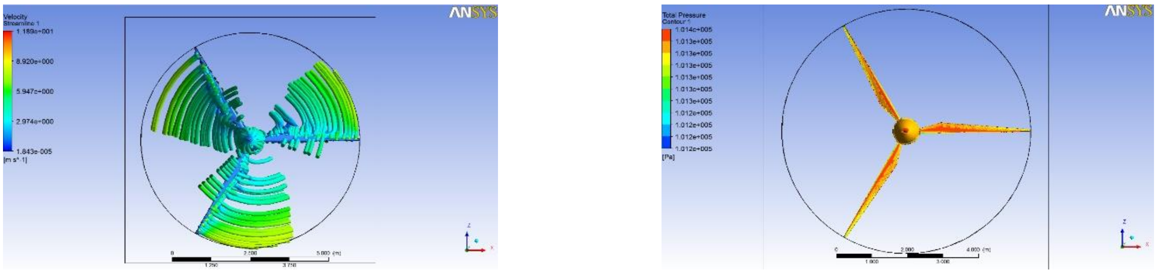
The rotor model is included in a cylindrical enclosure having a diameter of 7 m that coincides with the propeller blades width.



a) turbine rotor and air enclosure b) mesh network

Fig. 3. Analysis main domains and mesh network

Based on the values initially introduced, flow results were obtained with specific values of air circulation velocities at the level of the rotor blades and characteristic pressure being presented in figure 4.
The total force acting on the rotor blades in normal direction is calculated at 233.5 N for the inlet air velocity of 4 m/s and 246,3 N for the inlet air velocity of 5 m/s.



a) air velocity within rotor enclosure b) total pressure values

Fig. 4. Air flow analysis results

The air specific path-lines inside the fluid region are also presented emphasizing the principal parameters specific values related to air velocity, static and total pressure.
According with the air flow motion model are met the required conditions for the rotor blade entrainment in motion necessary to form a continuous rotary motion due to hydrostatic forces action on propeller blade.

5. Conclusion

The method of obtaining energy from wind force is highlighted as a viable alternative to the burning of fossil fuels. It has been several decades since the wind energy has registered an increase but more especially in the last period when the wind energy share in the total production reached the maximum values. Wind power plants have been continuously developed over the years in terms of rotor design and diameter, starting from about 12 m at the end of the 80s to approximately 120 m in diameter today, allowing the high power production of about 5 MW of green energy, thus reducing the energy consumption that comes from the sources with a negative effect on the environment.
In this paper were presented theoretical aspects regarding the wind turbines operation method as well as a calculation model of velocity circulation and flow rate specific values of circulated air at the rotor blade contour level.
Also, on the basis of a three-dimensional model, an air flow analysis inside the rotor enclosure was performed based on the declared values for the air input velocity characteristic to regions of plains, hills and coastal areas in Romania.

The results are presented in terms of air flow velocity, static pressure and total air pressure over the analyzed fluid area. Also the force values on the rotor blades are calculated allowing to establish the proper value of rotor torque according with inlet air velocity and analyzed model constructive type.
According to the obtained values it can be said that the conditions necessary for the displacement of the rotor blade are fulfilled based on the result of the hydrostatic forces that act directly on the blade surface and the blade geometry which allows the air to flow in a tangential direction to the contour curve.

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