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ASPECTS REGARDING THE ROTOR BLADE GEOMETRY

Abstract: *The consumers' energy needs and the variable wind potential have led the wind turbine producers to construct turbines that could efficiently operate in an as wide as possible range of wind speed power and domain. The rotor blade geometry is one of the factors that directly affect the turbine efficiency. The performance of the wind turbine depends upon blade and shape size but also upon their number. One of the main objectives in the design of the rotor blades lies in having an aerodynamic shape with high lift capacity and small drag force.*

Key words: *horizontal axes turbine, vertical axes turbine, rotor blade geometry, aerodynamic shape.*

1. INTRODUCTION

Wind energy has been known and put to work as early as Antiquity. In modern times, with the energy crisis of the 1970's, the concern of experts and poiliticians moved towards alternative sources of energy, among which wind energy, a non-polluting and renewable source of energy. The disadvantages of using wind energy are related to the random feature of wind and the small energy concentration per surface unit.

Among converting wind energy possibilities, the main interest lies in converting wind energy into electrical energy. From the measurements carried out, it was concluded that maximum 57% of it can be captured, and 42% of it can be transformed into electrical energy. In other words, from the overall wind power, the wind turbine captures and transforms in electrical energy about 24% [4]. Of course, such percentages have only an indicative value and vary dependent upon the turbine performance.

An important role in the performance of the wind turbine is given by the turbine type and the rotor blade geometry, aspects that will be dealt with in the present paper.

From the viewpoint of their construction, the majority of wind turbines are included in the dynamic turbines, defined by the motion of their component parts [1]. Two main categories are included in, respectively:

- Horizontal axis turbines, in which the axis is parallel to the wind direction and whose blades rotate in a plane that is perpendicular to the wind direction;
- Vertical axis turbines, whose rotor rotation axis is perpendicular to the air current direction and whose blades rotate in planes parallel to the wind direction.

Dependent upon the average wind speed and main wind direction, it is recommended to use certain constructive types of turbines, in specific climatic areas.

Research has found that an optimal wind speed for a maximum efficient conversion ranges between 14-16 m/s [4].

Because of the construction and implicitly the exposure of the turbine blades to the air current, it is necessary to make different approaches for aerodynamic features.

2. ROTOR BLADE GEOMETRY

2.1 Aerodynamics of blades profiles

Aerodynamics studies the motion and respectively the general gas flow, including air flows and their interaction with the solid bodies.

In order to understand the way in which the blade shape influences turbine performance, we will present the general case of a solid exposed to air current. Thus, in Figure 1, it is shown the decomposition of forces $\vec{F}$ and moments $\vec{M}$ resulting from the action of an air current, of density **ρ** and speed **v** upon a solid body, relative to the reference system Oxyz.

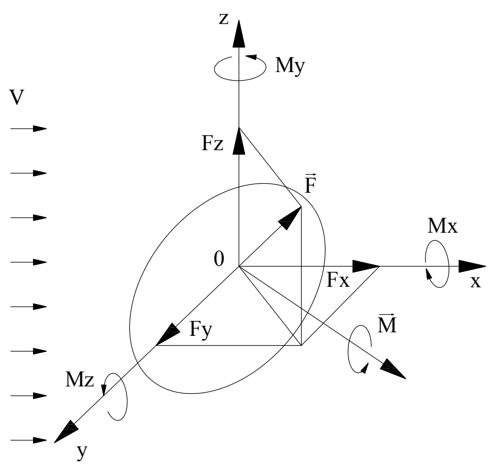


Fig. 1 Resolution of forces and moments [4].

Force F is decomposed into three components [1], namely:

- F_x – Drag force
- F_y – Drift force
- F_z – Lift force,

respectively, the resulting moment is decomposed also into the following components [1]:

- M_x – Rolling moment
- M_y – Pitching moment
- M_z – Gyration moment.

For wind turbines, a special interest is given to high lift capacity bodies and small drag force, i.e. to aerodynamic shaped bodies.

In order to study the influence of the blade geometry upon the efficiency of wind power conversion into electrical energy, i.e. the maximum captured power, one makes appeal to Betz's mathematical model designed for the two types of turbines [5]. The model studies the equilibrium of forces acting upon the turbines, by applying the theorem of fluid mass impulse at the input (A_1) and output (A_2) areas of a tube control surface (S_c), with a constantly equal section area to the area of the surface of the blade described by the helix type rotor (A).

The calculation diagram for the application of Betz's model to the horizontal axis turbine is given in Figure 2, while Figure 3 presents the calculation diagram of Betz's model in the case of vertical axis turbines.

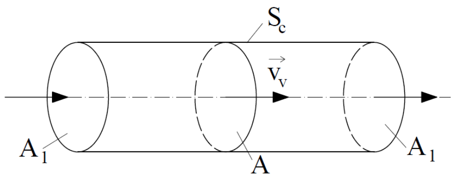


Fig. 2 The scheme for the application of Betz's model to the horizontal axis turbine.

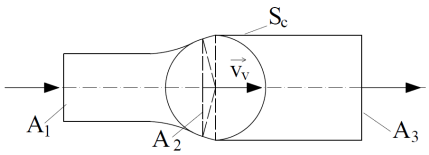


Fig. 3 The scheme for the application of Betz's model for the vertical axis turbines.

Applying the Betz's mathematical model it yields the maximum captured power as [6]:

$$P_{max} = c_{p\_max} \cdot \rho_{aer} \cdot A \cdot \frac{v_v^3}{2} \tag{1}$$

where,

$c_{p\max}$ = represents the maximum coefficient of wind captured power or Betz's coefficient;

ρ and **v** were previously explained;

A= the surface or the area covered by the turbine rotor during the motion of rotation.

The research studies show that the theoretical coefficient varies in the case of horizontal, respectively vertical axis turbine, namely:

$c_{p\max} = 0.593$, represents the Betz's coefficient, for the horizontal axis turbine;

$c_{p\max} \approx 0{,}53$, represents the Betz's coefficient for vertical axis turbines.

Many research studies have concerned with turbine geometry and implicitly with blade geometry, as it is known that the turbine performance depends both upon the wind speed and the area covered by the turbine rotor [6].

2.2 Horizontal axis turbine blade geometry

At present, horizontal axis turbines are most widespread, and relative to their size, they can be used for both high and low wind speeds. Function of wind direction, they can be built upwind or downwind type - see Fig. 4.

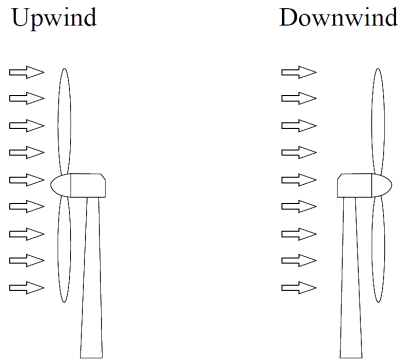


Fig. 4 Types of horizontal axis turbines [5].

The shape of the blade profile is selected after research and experiments in air tunnels as well as relative to previous experience. They can be built with only one blade with a counterweight (in areas with strong winds), called one blade turbines, or with two or three blades, also called multiple-blade turbines.

The turbines with several blades are more balanced and produce less vibrations [7].

Fig. 5 presents the geometrical characteristics of the aerodynamic profile of a blade [1]:

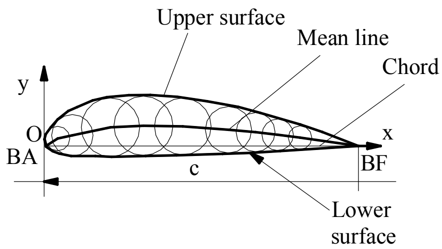


Fig. 5 Section through the blade [1].

- median line or mean line, which is the geometrical locus of the centers of the circles inscribed in the profile;
- leading edge (BA) is the part which comes first in contact with the air flow;
- trailing edge (BF) is the opposite part of the leading edge;
- chord (c), which is the segment between the leading and trailing edges;
- upper surface is the part of the profile with maximum curvature;
- lower surface is the less curved part of the profile.

Calculations and simulations have shown that the optimal shape for a blade contour is hyperbolic [3]. As the building of a hyperbolic blade is difficult and quite expensive, it is approximated with good results – as energy conversion performance, with the trapezoid and even rectangular shapes for the rotor blades.

The development of aeronautic industry and the study of blade shape provided premises for defining optimal shapes, of high lift capacity and small drag force, as are the NACA (National Advisory Committee for Aeronautics) series blades or similar ones.

Another particularity of rotor blade geometry is that the blades are twisted, which determines their aerodynamic shape, adaptable to variable wind speeds [3,4]. In the exploitation, the turbines start to rotate the blades slowly, and as they come into the nominal conditions of operation, the rotation speed increases substantially. This is possible through the construction of the blade, which must be more twisted to the base than at the top, causing a pronounced manifestation of the lift phenomenon.

As mentioned in the previous paragraph, the conversion efficiency is proportional to the square of the air current radius created by the blade rotation. There are various means that can lead to its increase. In Fig. 6, an example is given of a blade for a small power turbine built in the rural area of Alba County, which proved to be more efficient than the classical trapezoid shape as the area of the created current was increased due to the geometrical shape of the blade.

It is evident that energy efficiency is joined together to blade shape and that the previous calculation formulae show that trapped (captured) power is proportional to the cube of wind speed. In this respect, one of the methods that gives favourable results consists in caging (encasing) of rotors to increase rotor speed – Fig.7. This method is mainly applicable to small power turbines.

Fig. 6 Geometry of an energy efficient blade [6].

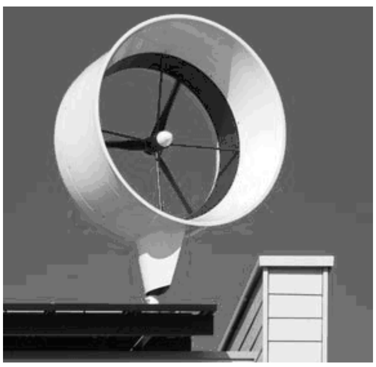


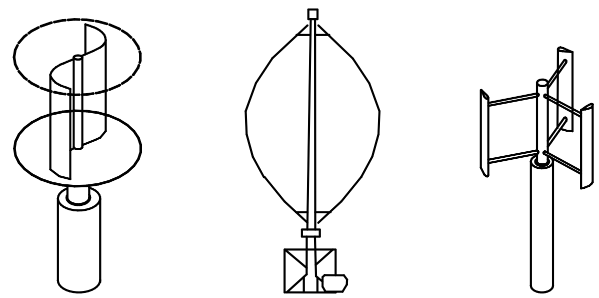
Fig. 7 Horizontal turbine encased [6].

2.3 Vertical axis turbine blade geometry

The vertical axis turbines mainly present advantages related to the operation at low speeds at values of about 2.5 - 4 m/s, respectively. Moreover, they do not need to be oriented relative to the wind direction.

The vertical axis turbines can be included in the following main categories – see Fig. 8 [5]:

- Savonius Turbines → they operate on the principle of traction differential and are characterised by high drag force.
- Darrieus Turbines → whose function is based upon the periodical variation of the incidence, and are characterised by high lift capacity; they are put at the basis of modern turbine design.
- A case derived from the Darrieus turbine is the H-rotor turbine- with straight blades. From an aerodynamic viewpoint, they are beneficial because the entire span of the blades actively takes part in energy production, while curved blades ends are less active, by comparison. A disadvantage consists in the larger tensions induced (large bending stresses in the blades). In this kind of turbines, the number of the blades can exceed four.



a. Savonius turbine b. Darrieus turbine c. Straight blade turbine

Fig. 8 Main types of vertical turbines [3,5].

The rest constructive types of turbines in the market are variations of the previously described kinds.

Aspects concerning the geometry of the two types presented above will be dealt with as follows.

Savonius turbines are made up of two semicylinders whose directrices can be a circle, ellipse, parabola (or sections of these) with dephased axes [5,6] – Fig. 9.

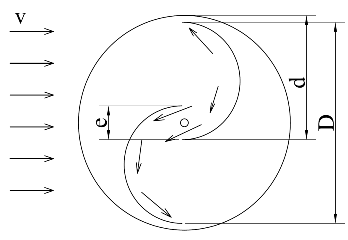


Fig. 9 Savonius vertical axis turbine [6].

The aerodynamic couple is due to the difference of the forces exerted by the wind upon the concave or convex portion and consequently of the successive deviation of the current, made by the blades. As only the aerodynamic friction effect is used, the power coefficient cannot exceed the theoretical value of 0.35, in practice being under this magnitude, in the interval 0.2-0.3. It is beneficial however, as it operates at small speed, of magnitude 2 - 4 m/s [7].

To improve the performance of this kind of turbines, several methods have been implemented, such as [5,6]:

- definition of the optimal overlapping of rotor blades – see Fig. 9; for small speed values, studies recommend a ratio of e/D= 0.15 – 0.25;
- increasing the number of blades, though practically because of turbulence related to wind direction, its effect is not spectacular;
- increasing the number of rotor levels to two or three (see Fig. 10), dephased at various angles so that the couple at the electric generator is more constant;
- fixing concentrators to increase the speed of the air at rotor inlet and to direct wind towards the blade concave portion; in spite of higher turbine performance, this measure is applicable only in areas with constant wind speed; when the wind speed is not constant, the measure is detrimental.

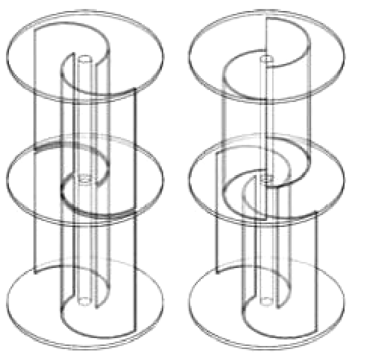


Fig. 10 Savonius turbines with more levels and various overlapping degrees [2].

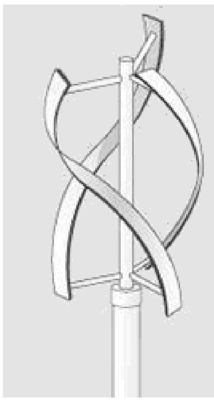


Fig.11 Types of helix blade rotors [8].

Darrieus turbines are defined by quite a high power coefficient, $C_p = 0.43$ [6]. The aerodynamic blades allow for a rotor the rotation at a speed higher than that of the wind.

Such turbines are built with two or three curved blades. Often used is the troposkien curve, which reduces the bending stresses due to centrifugal forces. It results by rotating a catenary curve around a vertical axis so that the blade will be subjected only to tensile stresses. The shape of such blades is more difficult to build and consequently H rotor turbines were developed with linear shaped blades. Higher efficiency is met with helix shaped rotor blades. – Fig.11.

3. CONCLUSIONS

One of renewable energy sources which is at present successfully put to work is wind energy. Various types of turbines can be recommended to be built in relation with the wind level area and condition of in site arrangement.

Horizontal axis turbines can be used for both high and low wind speed, dependent upon rotor size and power range for which the rotor was designed. Vertical axis turbines, though designed for a smaller power coefficient, can be used for quite small wind speed and in such situations the Savonius turbines are advisable. The disadvantage of this kind of turbines lies in the additionl starting systems required and the consumption of a part of the produced energy, for this purpose.

After the application of the theory of aerodymanic flow and of the measurements carried out in wind tunnels, it was presented how the energy performance of the wind turbines are significantly affected by the rotor blade geometry. The original contribution refers to some recommendations regarding the construction of Savonius turbines as result of a reserch developed by a team of Department of Building Services Engineerig of Technical University of Cluj-Napoca.

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