MAXIMIZING ENERGY EFFICIENCY IN THE CASE OF HORIZONTAL AXIS WIND TURBINE

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Abstract

Sistematizing some basic knowledge of turbines theory and filled with certain original solutions the present paper analyzes the optimization energy issue in the case of wind turbines. The exposed background consists on some mathematical model regarding the extracting energy maximization from wind valorization.

The developed methodology is presented in the following steps: optimization problems formulation, preparatory steps, finding the so called "desirability curve" and the last stage of the optimization process is to determine the "first geometry" or initial geometry.

Key words: wind turbines, optimization process, energy maximization

INTRODUCTION

In the last years a major interest in renewable energy resources has been observed.

The performance of the wind turbine can be investigated through mathematical models and also verified by experimental measurements. The achieving of aerodynamic performances, kinematics and energy curves of the aeolian turbines depend on the choice of certain geometry. In developing of turbine blade geometry are used improved contours (airfoil) chosen and positioned so that obtained performances for certain site-specific conditions, to be optimal.

Between various types of wind turbines the rapid axial horizontal wind turbines are the most development ones. Many studies are also elaborated taking in consideration the turbines with vertical axes. Such a study was presented by the first author in the paper (Dubău, 2009). Similar studies can be consulted (Gyulai, 2000, Gyulai-Bej, 2000, Gyulai et al., 2000). For the horizontal turbine H2500 we can consult the paper (Dubău, 2007). In this context we also recall the paper (Bej, 2003).

A horizontal-axis wind turbine (HAWT) is a wind turbine in which the axis of the rotor's rotation is parallel to the wind stream and the ground. The purpose of the rotor is to convert the linear motion of the wind into rotational energy that can be used to drive a generator. The same basic principle is used in a modern water turbine, where the flow of water is parallel to the rotational axis of the turbine blades.

The energy conversion process that turns wind power into electric power goes through three major conversion steps namely the aerodynamic, mechanical, and electrical conversion. At each step, some energy is lost and the final electric power is less than the total wind power we started with.

Depending on their type, size and location, wind turbines are currently capable of producing between 50-60 KW of propeller diameters starting from one meter to 2 - 3 MW power at 60-100 m propeller diameters, most of them generating between 500-1500 KW.

Horizontal shaft windings are most used because their aerodynamic efficiency is superior to that of vertical axes, are less subject to significant mechanical stresses and lower cost (Stanciu et al., 2015).

MATERIAL AND METHOD

The wind passes over both surfaces of the airfoil shaped blade but passes more rapidly over the longer (upper) side of the airfoil, thus creating a lower-pressure area above the airfoil. The pressure differential between top and bottom surfaces results in aerodynamic lift. In an aircraft wing, this force causes the airfoil to rise, lifting the aircraft off the ground. (see Fig.1.). For more details we can consult the works (Bird, J. 2007 and Bird, J. 2007 Fifth Edition) Since the blades of a wind turbine are constrained to move in a plane with the hub as its center, the lift force causes rotation about the hub.

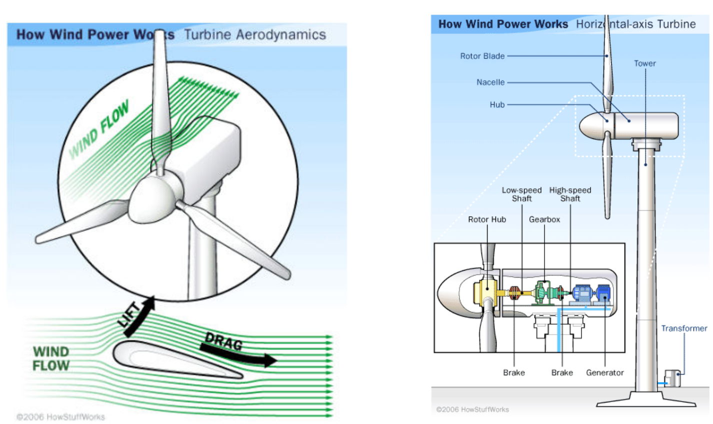

Fig. 1. Wind power impact in HAWT

In addition to the lift force, a drag force perpendicular to the lift force impedes rotor rotation. A prime objective in wind turbine design is for the blade to have a relatively high lift-to-drag ratio. This ratio can be varied along the length of the blade to optimize the turbine's energy output at various wind speeds.

Optimum performance is built through iterations “geometry-performance” in order to maximize the energy extracted from the wind for exploitation.

In the last years a major interest in renewable energy resources has been observed. Many researchers have had to deal with optimizations process in wind turbine field (see (Benini-Toffolo, 2002), (Giguere-Selig, 2000), (Jureczko et al., 2005)). We also recall the papers (Morthorst, 2009, Xudong et al., 2009).

By optimizing the construction solution of the wind turbine blade, we understand the obtaining of those aerodynamic outlines that achieve a desired functional feature for a certain application. We will refer to constant-speed turbines with power-limiting braking and aerodynamic braking by dividing the blade. To develop a working methodology, two of the most important steps are presented below.

For the first preparatory step we analyze the connection between power and turbine dimensions as well as the type of turbine (its speed). Using the energy supply analyzes of the sites, it is also possible to choose the profile family. Finally, the turbine diameter, installation power, installation speed and turbine speed are the result. An energy balance is made for the power chain from the theoretical wind extracted to the one obtained at the terminals of the electric generator.

For the second one it should be develop the so called “first geometry”. We will take into account that the installation point and the optimal ($C_{P\max}$) point do not overlap. The two points of exploitation are distinctly estimated and a compromised geometry for the optimal point and the point of installation is elaborated. The characteristic curves associated with the blade geometry are then calculated. They are represented by two families of curves: operating curves and non-dimensional curves.

In order to construct the operating curves we need some characteristic parameters, namely: (v) wind speed, (n) rotation speed, (C_p) power coefficient. It follows the dependence of the power turbine (P), the dependence of the moment at the engine line axis (M) and the dependence of the axial force (F_a) as functions of rotation speed, mass density of air (ρ), the dimensions of turbine (D) – (the diameter and the exposed area) and finally the wind speed. Thus we can obtain the general form of the power operating curve which is $P = f(D, \lambda_0, v, n, \rho)$. Finally, we can present also the others curves regarding the moment and respectively the axial force: $M = f(v,n)$ $F_{ax} = f(v,n)$. The forms of the non-dimensional curves are $C_P = f(\lambda)$, $C_M = f(\lambda)$ and $C_F = f(\lambda)$. The characteristic number, namely rapidity of the turbine, is defined by $\lambda = \frac{\pi \cdot n \cdot R}{30 \cdot v}$, where n is the (rotation) speed turbine [*rpm*]. Throughout the work, the power we are referring to is the one at the turbine shaft.

The optimization of the blade geometry consists in the successive modification of the initial geometry in order to obtain characteristic curves close to those formulated as "desirable curves". The "desirable curves" are approximated on the basis of accumulated knowledge, aiming at power regulation by breaking the boundary layer, two objectives:

A. In the area of inferior powers to that of installation, the power maximization is required;
B. In the area of higher speed it is required to cap the power at the installation level and maintain it within a wide range as much as possible in the installation speed range - the maximum operating speed.

For the protection of the aggregate in this regime also aerodynamic braking is triggered.

RESULTS AND DISCUSSION

The optimization of the wind turbine for an aerospace plant has the ultimate goal of maximizing the extracted wind energy, for recovery, under the conditions of a certain site. This translates into achieving a turbine operating curve with an allure that maximizes the extracted energy.

The new generations of wind turbines are equipped with rigidly mounted blades on the rotor hub that adjusts its power by removing the boundary layer on the blade extruder, so the operating curves have a distinct shape.

Achieving such a goal commonly referred to as the „desired curve" is accomplished in several steps, by successive corrections, starting from an initial geometry („compromised geometry").

We will continue to operate with general relations from turbine theory:

$$P = C_P \cdot \rho \cdot \frac{v^3}{2} \cdot S, \quad S \cong \frac{\pi D^2}{4}\left(1 - \frac{d^2}{D^2}\right).$$

We also use the well known relations $\lambda = u_R / v, u_R = R\omega$ and $\omega = \frac{\pi n\,[rpm]}{30}$ where we have used the following notations:

S – Area swept by the turbine,
R – Radius of the turbine,
P – Power turbine,

r – The diameter of the hub,
M – The moment at the engine line axis,
F_a – Axial force,
ρ – Mass density of air [kg/m^3],
v – Wind speed [m/s].

Using the mathematical model we have conceived a "desirable curves" which is posted in Fig. 2, by making use a computer simulation. There are also presented the exploitation and a-dimensional characteristics for the considered turbine. For the input data we have considered the power utilized by the turbine $P \cong 700kW$, $D = 35m$, *n=20 rot/min* the (rotation) speed turbine, mass density of air $\rho = 1{,}1\ kg/m^3$.

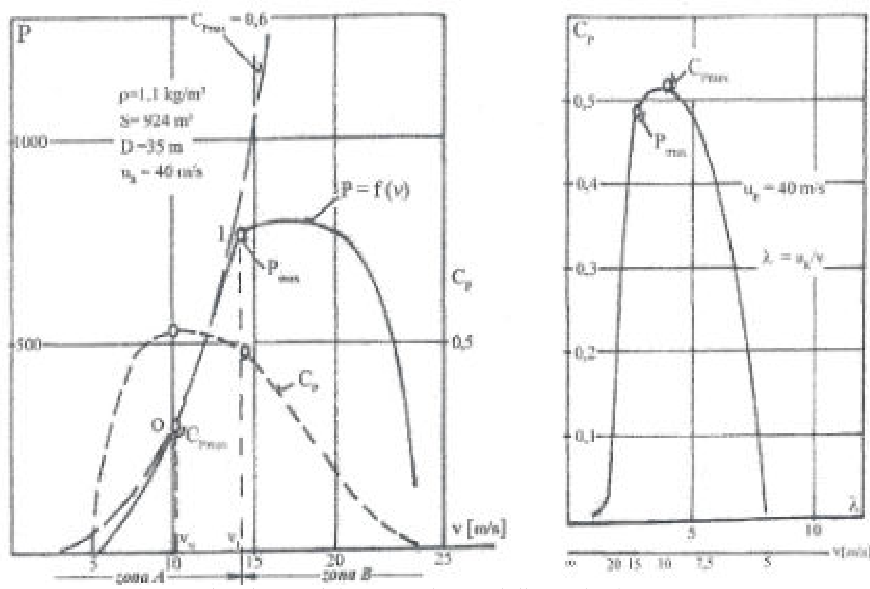

Fig. 2. The shape of the operating and dimensionless curves

On the curves, two operating points are marked: O (optimal) - corresponding to the maximum of the power coefficient and I (installation) - corresponding to the maximum power exploited.

The operating curve has two distinct branches: one, in area A, of powers lower than P_{max}, respectively of wind speeds and second in zone B, of high wind velocities where the turbine tends to achieve higher powers than P_{max} value. The maximum power (installation) is that at which the machine line is sized as an aeroelectric assembly.

In area A ($P \le P_{max}$), the goal is to maximize power coefficients. In the second area of the curve, B- the objective is restriction the power to the value P_{max}. In the plane of the dimensionless curve $C_P = f(\lambda)$ this area corresponds to the small values of the characteristic numbers. Within the objective for this area the difficulty consists in controlling the power coefficients to keep close to the maximum value in a wide range of van speeds (14-25m / s in the case of the studied turbine).

This control can be obtained by designing the separation of the boundary layer (using aerodynamic methods) with controlled evolution along the palette radius. This optimization of power restriction is performed acting primarily on the angle of installation of the profiles in the pallet component.

For example, the experience of the Aeroenergetics Research Center at the „Polytechnic" University of Timisoara shows that it is rational for the design control of the separation to use the large (peripheral) area and less the turbine hub area. Thus, the separation must begin at the top of the blade and be gradually extended to smaller radii. In this respect, by analyzing the phenomenon, one can evaluate the effect of the power regulation by not participating in the energy transfer of a circular corona (Fig. 3), the yield of which becomes very small after the separation of the boundary layer.

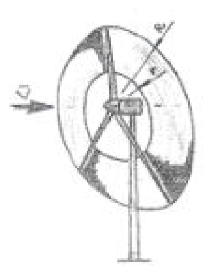

Fig. 3. The energy transfer for the circular crown

In Table 1, for the particular case of the analyzed turbine, the evolution across the palette from the periphery to the hub, of the palette section which enters in detachment function of wine speed is shown. The power coefficients of the turbines required to achieve the power restriction at the level required by the desired curve in Figure 2 are also calculated.

Table 1

Evolution of the palette section

v[m/s]	15	17,5	20	22,5	25
C_P	0,46	0,32	0,19	0,08	0
r/R	0,96	0,80	0,62	0,40	0
r [*m*]	19	16	12,5	8	The entire palette
R- *r* [*m*]	1	4	7,5	12	The entire palette

For example, at 17.5 m / s for power restriction, a power factor of 0.32 is required, the detachment extending from the periphery to 0.8 m of the entire palette length.

CONCLUSIONS

Such an analysis can therefore offer the designer, for generating compromise geometry, load distribution information to control the evolution of turbine power. Similarly, other analyzes can be made on the desired curves.

This study highlights the importance of certain parameters of wind turbine for different rapidity, in the process of construction and development of such aero-electrical aggregates and their optimal functioning. The results showed the accuracy of the model in wind turbines performance monitoring.

The optimization process of the construction of wind turbines is a continuing concern for researchers and manufacturers in the wind power field, having as finally purposes, solutions capable of performing a maximize economic efficiency of these aggregates. In order to fulfill this desirable objective it should be identify certain way to improve the energy recovery, minimizing costs for technical solutions, high reliabilities and good maintainability.

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