

Aeolian potential estimation in the hill areas

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Abstract This paper presents some of the preliminary results of the anemometrical measurements campaign on the hill areas. These areas could benefit from the installation of some small dimension wind generators.

The analysis refers to areas known as “marginal”, that is, they have an energetic density and medium speed that do not really justify, from an economic point of view, the investment in a high dimension wind station. (according to a vague classification, the areas considered “poor” have less than $200W/m^2$ and the “marginal” areas have between 200 and $300W/m^2$). The final decision will be determined by the wind statistic analysis from the areas of this type, with the help of Weibull distribution and some other parameters designated to quantify the zone turbulence. It will be demonstrated how one of the most interesting characteristic of this area type, that is the high energetic density of the speed distribution “heads” is significant and not only the relatively small value of the medium speed.

Keywords: Aeolian , Weibull distribution, orographical influence

I. INTRODUCTION

Conventionally, not long ago, they were considered recommended areas for setting the wind turbines:

- on the seaside;
- small orographical influence;
- reduced land rugosity.

Nowadays other areas have started being analyzed and considered to have “wind source”:

- the inside of the continent
- the high orographical influence
- the high rugosity of the land.

In the National Meteorological Administration network, all the measurements are made at about 10m from the soil. Thus, the historical data regarding the multiannual average speeds are measured at this height.

In the eolian industry, most of the wind turbines have the rotor at a height of 60 m from the soil.

Due to the fact that the superficial layer has been extensively studied in different fields of activity (from agriculture to meteorology, from oceanography to engineering), some different wind speed profiles have been elaborated. All of them start from the fact that the movements present within the layer are of turbulent type, and the turbulence is mechanical, as long as it is assumed that the range is quasi-adiabatic, stratification is made in neutral hydrostatical conditions and the convection phenomenon is thus insignificant.

To describe the variation of the wind speed, three theories are used as regards the wind profile:

1. an exponent law;
2. a logarithmic profile
3. a diabatic profile

The vertical profile of the wind: The gradient wind reduces its speed close to the soil, fact that can be described by a logarithmic law. In order to apply this law, one has to know the two parameters:

- u^* is the shear velocity that includes the effect of the friction force;
- z_0 that represents the soil type (RUGOSITY)
- k is Von Karman constant equal to 0,4.

$$U(z) = \frac{u^*}{k} \cdot \left[\ln \left(\frac{z}{z_0} \right) \right] \quad (1)$$

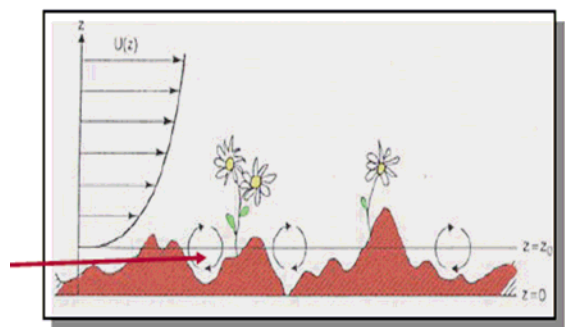


Fig 1. The Vertical Profile of Wind Velocity

Speed up effect due to hill. Jackson and Hundt Theory. This theory refers to not so abrupt hill inclinations and in neutral atmospheric conditions (or better said in atmospheric conditions that present only mechanical turbulences).

$$\Delta S = \frac{\Delta u}{u_0} = \frac{h}{L} \frac{\ln^2\left(\frac{L}{z_0}\right)}{\ln^2\left(\frac{l}{z_0}\right)} \quad (2)$$

When an incident air flow meets a relief form, the speed distribution on the vertical axe slightly modifies itself. Among the changes of the speed vertical profile we mention: the wind that initiates downhill slows down on the relief slope, then starts to accelerate and reaches the maximum speed around the top of the slope, where the curvature degree of the profile is the lowest:

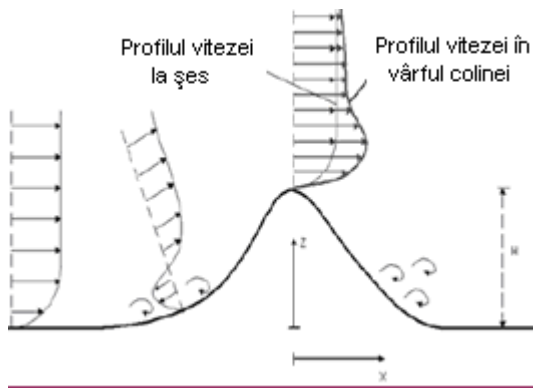


Fig 2. The „speed up” effect due to the zone orography

TABLE I. Speed calculated on the top of the hill at 60 m from soil

Month	Jan	Nov	Dec
Monthly average at 10m	3,1	3,0	3,2
Monthly average at 60m	4,30	4,14	4,10
Average speeds on the top of the hill	5,24	5,05	5,43

The wind speed is a vector with a modulus and direction that modify themselves very fast in time, and because of that, the three components that characterize the speed $v_x(t)$, $v_y(t)$, $v_z(t)$ will be treated as random variables. The only components of interest in the wind industry are $v_x(t)$, $v_y(t)$. Doppler anemometrical devices are being used, devices that are capable to register with a very high sample frequency these components: wind speed and direction.

Because the fixed wind stations that are strongly influenced by the wind direction are somehow out of date, this paper focuses on the variation of speed modulus in time.

The distribution of the Weibull probabilities (Wind statistics) is the one that better describes the wind variable.

$$p(u) = \frac{k}{c} \left(\frac{u}{c}\right)^{k-1} \cdot e^{-\left(\frac{u}{c}\right)^k} \quad (3)$$

This type of distribution is characterized by two parameters: standard mean and deviation, specifically referring to U_{10}

c is a scale factor, biunivocal bound to the medium speed. To determine this factor we use:

$$U = c \cdot \Gamma\left(1 + \frac{1}{k}\right) \quad (4)$$

where Γ represents the Euler function:

$$\Gamma(x) = \int_0^{\infty} e^{-t} \cdot t^{x-1} dt \quad (5)$$

From a physical point of view, the dimensions of the c factor are those of a speed. k is a shape factor, adimensional, that modifies the distribution symmetry, values very close to 1 represent distributions strongly asymmetrical, while values higher than $2 \leq k \leq 3$ determine symmetrical distributions, very similar to the Gaussian ones. In a particular case, for $k=2$, the Raileigh distribution is achieved, and this can be used for evaluations when only the medium speed is known.

II. DETERMINATION OF PARAMETERS K AND C

The fundamental problem before starting the analysis of the wind distribution for the connection of characteristics wind - wind turbine consists in the determination of parameters k and c . They are determined by starting from the cumulative distribution curve of the wind speeds.

TABLE II. Determination of parameters k and c

Month	Average speed	parameter k	parameter c
November	4,6	1,473	5,285
December	5,0	1,478	5,796
January	9,7	1,481	9,359

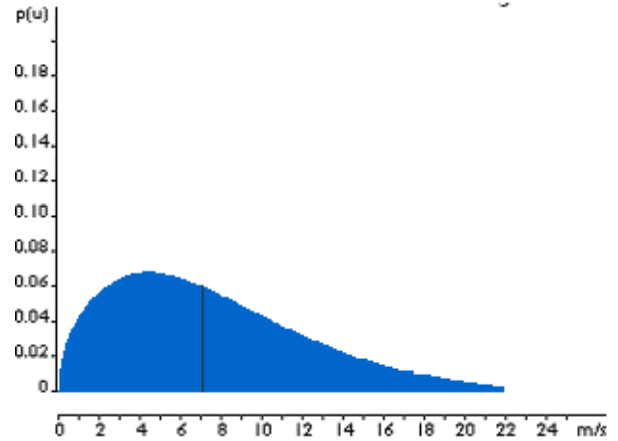
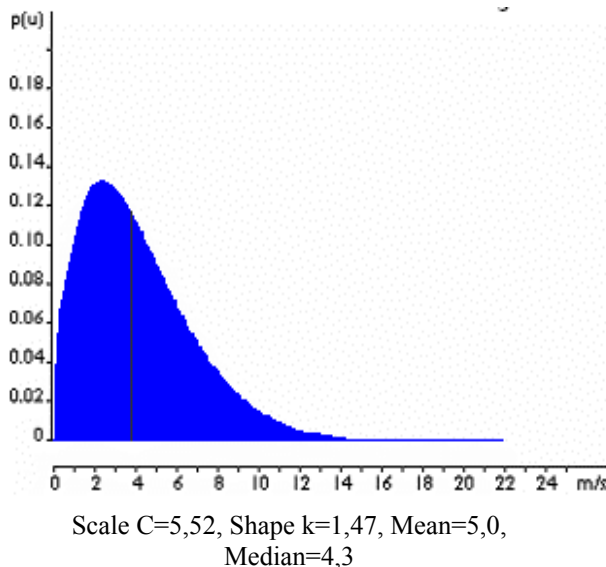
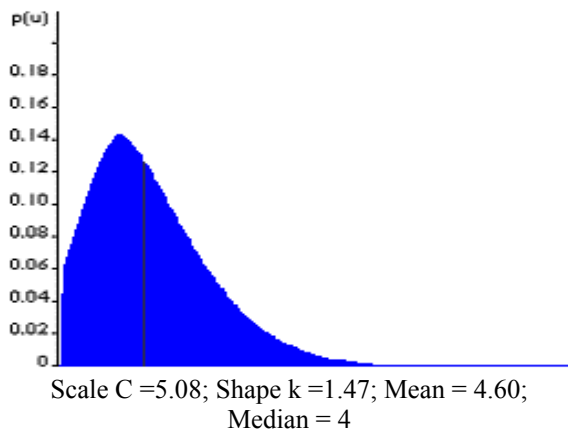


Fig 3. The figure proves the influence of the two parameters c and k for a temporal series of data, for november, december and ianuary months

The advantage of a statistical approach is that it allows successive evaluations of productivity, independently from the gross measurements data, but in the same time it condenses very well the statistical properties of the temporal series.

This Weibull distribution intends first to determine the mean, then the variation and finally the energetic density (proportional to a third power wind speed). We are obviously interested in the medium wind speed, but in this paper we intend to go into details as regards the dispersion influence and the way it is interpreted.

The most important is the standard deviation σ , which measures in fact the turbulence (or the turbulence intensity "TI"). From a N temporal series given by the speed $u_i (i = \overline{1, N})$:

$$TI = \frac{\sigma_u}{U} \quad (5)$$

- U is the medium speed;
- σ_u is the standard deviation;

From a physical point of view, the turbulence derives from the dispersion of the wind kinetic energy into thermal energy during the process of formation and destruction of the small whirlwinds of very small dimension. A precise description of these data is adequate to the sample (at least 1Hz), i.e. a high sensitivity of the used anemometer. The turbulence intensity expressed in percentage, is a fundamental characteristic as long as this project depends on it. The experience has proved that turbulence in its turn depends

on the medium speed within the interval taken into account.

Starting from the land structure, the turbulence will be higher when:

- The zone topography is complex; it has hill sides with steep slopes, valleys, peaks, etc.
- The land has a “rugged” covering. Taking into account the air fluid dynamics, the rugosity is determined by the human buildings, trees, forests, isolated buildings, etc. The wind industry defined these classes of rugosity which start from a calm sea, fields, steppes till forests and cities .

The turbulence intensity TI may be sufficient, but in fact it is only a small part of information from the temporal series of data. We mention only the methods used without going into mathematical details:

1. The autocorrelation. The autocorrelation function studies the temporal aspect of the situation answering to: “how it is correlated the speed $v(t)$ at a time t , being given speed $v(t_0)$ at a time t_0 ”.
2. The duration/ time specific to turbulence: the duration when the speed variations are correlated, meaning there is an evident “memory” effect of the fluctuation. ($< 10\text{sec}$) The specific turbulence Duration/Time: the duration when the speed variations are well correlated, meaning the moment when there is an obvious variability “memory” effect. ($<10\text{sec}$) The specific duration is easy to find by multiplying time with the medium speed, and from a physical point of view it represents the medium size of the whirlwinds.
3. The density function of the spectral power, the “turbulence spectrum” (PSD power spectral density). The spectral density function proves how much the energetic content differs from the wind frequencies.

On a temporal scale of observations, very different phenomena can be highlighted: from the atmospheric fronts of over 3-4 days (synoptic peak), to day/night cycle around cities, coasts, valleys (diurnal peak), till the micro whirlwinds of only some centimetres (turbulent peak). An interesting characteristic of the “wind spectrum” is the so-called “spectral gap” which consists of an obvious energy gap in the range from $T=10\text{min.}$ and $T=2\text{h.}$ (see Fig. 5)

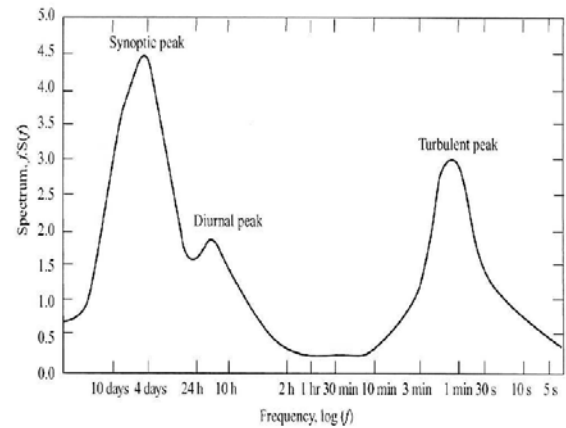


Fig 4. Temporal scale of observations

The monitorization of Oradea area has started at the beginning of November 2006 and it lasted shortly, so as to draw some definite conclusions. These measurements must last for 18 months; it is a short but sufficient period of time, because there is the Airport meteorological station which is in the possession of some historical data, to whom the measured data can be correlated. Nevertheless, some clear tendencies can be already observed:

- The gross measured data “tell only the history” of the local wind, underlying the episodes with strong wind and atmospheric calmness.
- The blue histogram shows the measured data, the red curve proves the Weibull distribution which reproduces accurately both the medium speed and the energetic density of the measured data.

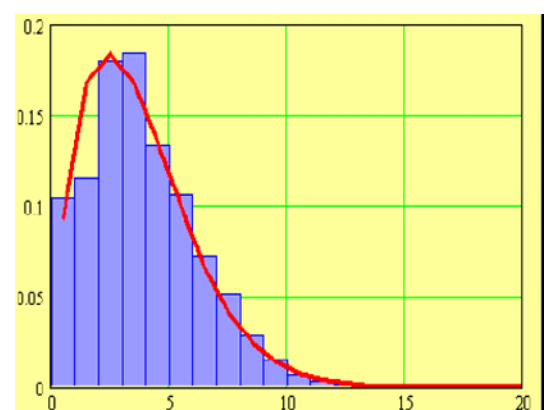


Fig 5. Demonstrates the Weibull distribution which reproduces accurately both the medium speed and the energetic density of the measured data.

Analysis of the k factor:

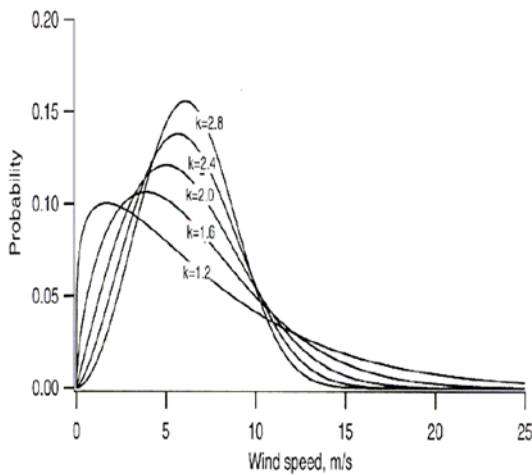


Fig. 6. The effect of the k factor variation for a speed of $u < 8\text{m/s}$

TABLE III. The following effects which influence immediately the wind characteristics of the area can be observed from analyzing this graphic.

At the same medium speed	$k < 2$	$k > 2$
Speed dispersion around medium value	It increases: a smaller value of k makes the distribution flatter and more asymmetrical, causing a higher speed dispersion, and as a consequence, it makes the higher speeds more "likely"	It decreases: a higher value of k indicates a distribution that aims at a symmetric Gaussian, with a more and more narrower peak (so, wind speeds f , constantly around the average)
High speeds (> than the average)	Become more likely	Become less likely
Low speeds (< than the average)	Become less likely	Become less likely
Energetic density	increases	decreases
The committed error using only the medium speed for evaluations	increases	decreases
A traditional wind turbine (of a nominal speed equal to twice the zone medium speed)	Produces more energy a year and is liable to higher charges	Produces less energy a year

TABLE IV. Comparisons between measured and estimated values

Month	Estimated values of wind speed	Measured values of wind speed
November	5,05	4,6
December	5,43	5,0
January	5,24	9,7

In November and December, the values are comparable. In January, the measured value is much higher. Possible explanations: Possible climatic changes that are not observable when mediation is made on long periods of time

To understand, if it is efficient or not to instal a wind turbine in a certain area, it is necessary to study the technical characteristics of the air-generator in correlation with the Weibull speed distribution.

A_F : The availability factor is a parameter that indicates the time rate in which the turbine can work and depends on the cut-in speed, respectively the cut-off speed.

C_P : The capacity factor is a parameter that provides the ratio between the really extracted energy by a wind turbine in a certain period of time and that which could be extracted if the turbine would have been working at a nominal power for the same period of time.

η : The output of the turbine is a parameter that reflects the efficiency of the turbine and represents the ratio between the energy produced by the wind turbine and the ideal energy produced by an ideal turbine ($< 0,6$ Betz's Theory).

TABLE IV. Efficiency parameters of the turbine

Efficiency parameters of the turbine	A_F	C_P	η
November	0,490	0,121	0,287
December	0,561	0,156	0,280
January	0,739	0,354	0,229

III. CONCLUSIONS

Because the measurements have been undertaken only for three months, this is not a complete study, but it is an indicator that can determine the continuation or ceasing of the measurements.

In January 2007, some very high monthly average values of the speed were recorded that can be explained only by climatic changes: the increase of the atmospheric calmness percent in comparison with periods of time with high wind intensities.

Oradea Hills are interesting from the viewpoint of wind potential, and for this reason, the measurements must continue.

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