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The Level of Calculation Errors in the Case of Using the Weibull Distribution for Estimating the Eolian Potential According to the Real Potential Based on Effective Measurements of the Weather Characteristics

The management of an investment program in wind power generators must consider the proper evaluation of the possibilities offered by the location where the park will be disposed and will operate: the available existing electric networks, access roads, the shape of relief, climate, extreme weather phenomena, the average wind speed, etc. Among the items listed above, the most important is wind potential of the area, quantified, measured mainly by multi-annual average wind speed. Evaluation, without special measurements, can be done based on general information such as measurements obtained from meteorological stations, using Weibull distribution for wind speed. When using the weather characteristics measurement results, the evaluation is closer to real multi- annual potential.

Keywords*: wind, wind speed, wind potential, wind specific power, energy, Weibull distribution*

1. Introduction

For over 100 years the concepts of economic development, technical progress, scientific research, culture and civilization, etc. became linked inseparably to the concept of electricity. All "developments" require, on one hand, higher consumption of electricity, but on the other hand is felt more and more tend to save and to consume less energy.

If fossil fuels were initially almost all energy suppliers (default and electricity), over time began to appear difficult background problems: hydrocarbons are (quantitatively) limited, and by burning them appeared unwanted effects, they involve increasing efforts to extract, transport and ease of use, access to them has become harder and more expensive, etc..

Apart from hydro resources, which were used directly, using wind power enjoyed (and enjoys) the attention. Although it is difficult to use (both technically and economically) because it is inexhaustible, is situated on an unprecedented upward trend. In addition, it is clean and the changes the wind turbines produce on flora and fauna are lower than collateral actions contained in other processes of producing electricity.

But, like hydrocarbons and hydro potential, wind energy - as resource - must be identified in places where it is cost-effective, and the operation can be done almost continuously to acceptable power levels etc. It meets all the typical characteristics of a resource, obviously with its features.

Wind practically beats everywhere. However, the exploitation of its energy in the framework of an investment must be made after a careful and thorough analysis of several factors. Depending on the wind potential of an area (dictated primarily by the average wind speed, and the frequency and stability) to determine whether investment in wind power is appropriate or not.

Assessment of wind potential in a point or an area, can only be based on measurement parameters (factors) of air.

Atmospheric parameter values can be obtained from weather stations, if any in the area, indicative of the websites that have general information on the movement of air masses and / or using facilities and specialized equipment to monitor atmosphere.

Substantive difference between data recorded at weather stations and those obtained from measurements, is the following:

- From weather stations are obtained single values for size and wind direction. In addition, generally anemometers (from weather stations) are arranged at small heights, the order of meters, which makes wind power to be affected (reduced) significantly influenced by the roughness of the arrangement. Until using modern equipment, wind direction and intensity values are read at a certain time interval, mediation is made somehow subjective, there is no basis of data recorded for well-defined intervals, allowing a calculation and hence an objective evaluation.
- Note: for a general estimate (in the absence of precise data and specialized), to conduct tests for determining the place of disposition of the poles anemometers, weather maps with information on wind intensity are very welcome and more than necessary
- the anemometers pillars (specialized) may have several anemometers at heights previously established, by which values of measurements of wind force can be obtained, averaged over the desired time intervals (pre-set);
- using LIDAR type installation that can monitor the movement of air masses to heights of several hundred meters;

- Disposal sites in the field of anemometers pillars can be chosen depending on the configuration of land, access roads, electricity transmission networks and existing distribution and especially the curves drawn (based on existing primary information) for the existing potential in the area.

2. Presentation of the Problem

2.1. The use of Weibull distribution

Based on the average wind speed for a given height, accepting Weibull type distribution (widely recognized in the field of wind energy), you can construct safety curves and the frequency curves.

Analytical expression for safety curve is:

$$FA(v) = 8760 \cdot e^{\left[-\left(\frac{v-a}{c}\right)^k\right]} \tag{1}$$

and for the frequency curve is:

$$FF(v) = \frac{8760}{c} \cdot k\left(\frac{v-a}{c}\right)^{k-1} \cdot e^{\left[-\left(\frac{v-a}{c}\right)^k\right]} \tag{2}$$

where the symbols used have the following signification:

v – Wind speed;
a – Location parameter;
c – Scale parameter;
k – Shape parameter.

Parameters of the distributions can be calculated with the relationships established and used by different researchers.

In this case we used the following relations:

$k = K\sqrt{v_m}$, K = 0,73 … 1,05

$$c = \frac{v_m}{-0.09562 - 0.1236 \cdot k + 0.68605 \cdot \sqrt{K} + \dfrac{0.51928}{K}}$$

$$a = -c\left(\ln\frac{8760}{T_0}\right)^{\frac{1}{K}} \tag{3}$$

$T_0 = 8760 - \Delta T_c$

$\Delta T_c = 3050 \cdot v_m^{-1.654}$

Giving speed values within 0 to 20 m/s, the two curves can be constructed (insurance and frequency). Their values thus obtained (duration of time intervals depending on wind speed) can be calculated the specific energy of air masses set in motion by the wind:

$$E_{sp}^{W} = \int \rho_{aer} \cdot \frac{v^3}{2} \cdot dt = \sum \left(\rho_{aer} \cdot \frac{v_i^3}{2} \cdot \Delta t_i \right) \tag{4}$$

where ρ_{aer} is air density and v_i is wind speed and Δt_i is the time duration on witch the wind has a certain speed (under the acceptance model Weibull distribution as a function of wind speed time average).

2.2. Using Experimental Measurements

Based on actual values of wind speed (measured with anemometers towers) can be determined the specific real power of moving air masses using the general relationship:

$$P_{sp}^{val\ mas} = \frac{1}{2} \cdot \rho_{val\ mas} \cdot v_{val\ mas}^3 \tag{5}$$

Based on this relationship, simplifying assumptions and values of experimental measurements a software was made whose results are very close to reality (through the use of real input values in admitted relationships and admitted assumptions).

2.2.1. Working Assumptions

The following simplifying assumptions were admitted:

- Is considered that the masses of air that strikes and drives the propellers generator, have the same speed (on the entire surface of the rotor) and equal to that measured or calculated (by extrapolation) for the height at which the rotor shaft is mounted;
- Neglects the temperature variation of the pressure and that of atmospheric air (from the point of arrangement of the measuring apparatus - about 5÷6 m and height of the turbine shaft h);
- Neglects the influence of humidity on its density (its manifestation for temperatures below 30 ☐C is insignificant);
- Is considered that the measured value is the horizontal component of velocity vector;
- The generators rotor is able to take and send full (forward) the kinetic energy of air mass that strikes;
- Air behaves in thermodynamic terms, as a perfect gas.

2.2.2. The Values of Experimental Measurements

Values obtained from anemometers posts for weather parameters are average values every 10 minutes for wind speed and temperature and air pressure.

2.2.3. Energy Calculation

Specific energy of moving air masses (for a certain period of time) will be the result of summation specific energies calculated for intervals of 10 minutes.

3. The Approach

Using, for power estimation (and energy as well) the specified monthly average velocity values of wind and accepting Weibull distribution, an likely value will be obtained.

Using, for the same computation, the experimental values (of weather feature) on 10 minutes averaged for specified period of time, will be possible to quantify, with high precision, the wind potential for a known location.

Taking in account that the purpose is to determine the errors lever between these two methods, for an easier approach, we will suppose that from thermodynamically and electrically point of view there is no loses (the generator efficiency is ideal for both cases).

By comparing those two sets of results will see the difference between Weibull model and real model. This is actually the purpose of present paper. The following figure presents the comparison mode of those two models.

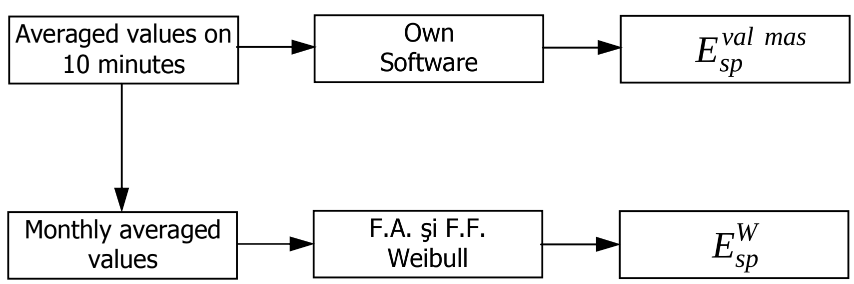

Figure 1. Comparison mode of the two models

4. Computation. Comparisons

4.1. Location. Conventions

For computations a specified location was chosen, on Semenic mountain's plateau and the geographical coordinates are the follow: 45°11′7,81″ N and 22°4′17,28″E. The altitude that the anemometrical tower is mounted is 1378 m.

It was agreed that the specific wind power is zero if $v<m_{min}$ and/or $v>v_{max}$, the values for v_{min}, v_{max} and height h are fixed from the beginning. This convention is respected from the design, fabrication and operation of the generators from technical, economical and safety reasons.

In the developed software the computation some conditions was implemented in order to avoid the unnatural values that can appear as a result of wheatear dysfunctions and/or measuring instruments and hardware damage. In case of data missing's the corresponding files or sheets are nonexistent.

4.2. Obtained results

Taking in account that the electrical energy is the finite product, we consider that it is the one to be compared for those two methods.

4.2.1. The results obtained from Weibull distribution

To create an image as relevant to the computation method that use Weibull distribution, a frequency function was computed for monthly average speed using for K coefficient values which include margins and his middle.

In table 1 are presented the values of Weibull distribution parameters (version with three variables) and the air density values for the three mounts. The averaged values of density were computed using the monthly averaged values for air temperature and atmospheric pressure.

Table 1.

Months	**v_m [m/s]**	**K**	**k**	**c**	**a**	**ρ [kg/m^3]**
July	5.617	0,73	1,730115	6,289558	-0,66304	1,046271
		0,94	2,22782	6,33901	-1,10465	
		1,05	2,488522	6,327474	-1,32411	
August	4.835	0,73	1,60517	5,38012	-0,55637	1,046387
		0,94	2,066932	5,454268	-0,93639	
		1,05	2,308807	5,454891	-1,12636	
September	5.091	0,73	1,647117	5,678502	-0,59043	1,054442
		0,94	2,120945	5,744805	-0,99045	
		1,05	2,369141	5,74146	-1,19003	

In table 2 was presented, for exemplification, a part from a sheet for frequency function and specific energy. For wind velocity values between 0 ÷ 3,75 m/s and above 20 m/s it was considered that the wind turbine doesn't working and the energy is zero.

Table 2.

v [m/s]	FF_{an} [h/year]	FF_{luna} [h/months]	E_{sp}^{W} [kWh/m²]
0,25	142,0886	11,84071	0
0,5	166,451	13,87091	0
0,75	187,7779	15,64816	0
1	206,3576	17,19647	0
....			
3,75	270,5741	22,54784	0
4	266,8247	22,23539	0,74445591
4,25	262,0073	21,83394	0,87682552
4,5	256,2431	21,35359	1,017941143
4,75	249,6504	20,8042	1,166396355
5	242,3443	20,19536	1,320613809
....			
20	0,571162	0.047597	0

The theoretical specifically electrical energy computed for analyzed months is presented in table 3.

Table 3.

Months	v_m	$E_{sp}^{wK=0.73}$	$E_{sp}^{wK=0.94}$	$E_{sp}^{wK=1.05}$	$E_{sp\,med}^{w}$
July	5,617	117,14	46,03	57,47	73,55
August	4,835	82,99	49,36	38,66	57,00
September	5,091	94,14	56,75	44,71	65,20

4.2.2. Results obtained by processing the measurements

Using the software presented in 2.2. the following results were obtained for specific energy (table 4).

Table 4.

Months	v_m [m/s]	$E_{sp}^{val\,mas}$ [kWh/m²]
July	5,617	110,51
August	4,835	69,03
September	5,091	89,58

4.3. Comparison between Two Methods of Estimating Wind Potential

The values obtained after computations can be compared, the exact form of figures and charts provided by the generic terms of frequency of speed produced by the two methods.

The comparison between those two approaching modes is synthesized value in the table 5, 6 and 7.

Table 5.

Months	$E_{sp}^{W_{med}}$	$E_{sp}^{val\ mas}$	$\frac{E_{sp}^{W_{med}} - E_{sp}^{val\ mas}}{E_{sp}^{val\ mas}} \cdot 100$
	[kWh/m²]	[kWh/m²]	[%]
July	73,55	110,51	-33,44
August	57,00	69,03	-17,43
September	65,20	89,58	-27,22
Average value			-26,03

Table 6.

Months	$E_{sp}^{W_{K=0.73}}$	$E_{sp}^{val\ mas}$	$\frac{E_{sp}^{W_{K=0.73}} - E_{sp}^{val\ mas}}{E_{sp}^{val\ mas}} \cdot 100$
	[kWh/m²]	[kWh/m²]	[%]
July	117,14	110,51	+5,99
August	82,99	69,03	+20,22
September	94,14	89,58	+5,09
Average value			+10,43

Table 7.

Months	$E_{sp}^{W_{K=0.94}}$	$E_{sp}^{val\ mas}$	$\frac{E_{sp}^{W_{K=0.94}} - E_{sp}^{val\ mas}}{E_{sp}^{val\ mas}} \cdot 100$
	[kWh/m²]	[kWh/m²]	[%]
July	46,03	110,51	-58,34
August	49,35	69,03	-28,51
September	56,75	89,58	-36,65
Average value			-41,16

In table 5 was presented a comparison between monthly specified energy computed using measured values of $E_{sp}^{val\ mas}$ and averaged monthly specified energy (for those three values of K) computed using Weibull distribution $E_{sp}^{W_{med}}$.

Tables 6 and 7 presents the comparison between monthly specified energy computed using measured values of $E_{sp}^{val\ mas}$ and averaged monthly specified energy computed for K = 0,73 ($E_{sp}^{W_{K=0.73}}$) şi K = 0,94 ($E_{sp}^{W_{K=0.94}}$). Those last values are bigger and respectively smaller than the values computed based on measurements.

To be easier and suggestive comparison, the graphical representation of frequency function computed for Weibull distribution (with three values for variable K) and graphical representation for real frequency function (prepared based on experimental values averaged at 10 minutes) was presented for august 2009 on the same coordination system in figure 2.

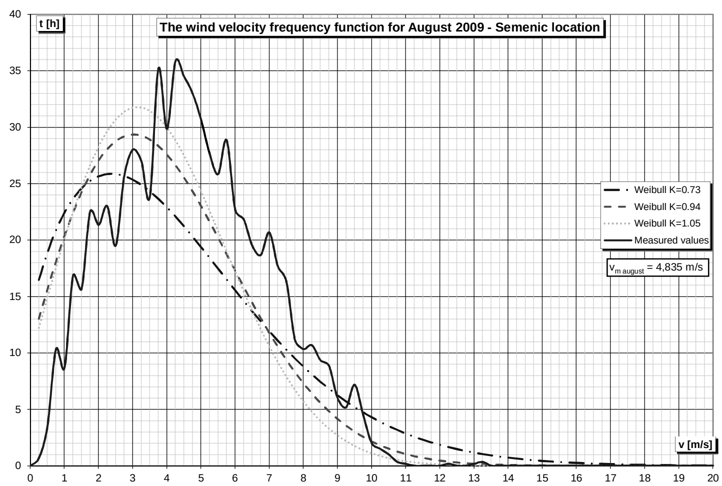

Figure 2. Graphical representations of frequency functions

5. Conclusions

By using the Weibull distribution a more useful wind potential evaluation is made compared to evaluation based on averaged wind speed.

Comparing the results it can be concluded obvious that the energy values (using Weibull distribution) varies in a wide range compare to actual values from overestimated of 10,43% to an underestimate of -41,16%. This variation is generated by the value chosen for the coefficient K.

Since using the values K = 0,73 and K = 0,94 were obtained values for specific energy monthly, which takes the real values, we can claim that there is a value of coefficient K for which, theoretically, energy calculated (using the Weibull distribution) is correct. Optimal choice of coefficient K is very important and therefore it should be done with maximum attention to avoid under or exaggerated wind potential overstatements.

6. Acknowledgement

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References

[1] Bej A., *Turbine de vânt*. Editura Politehnica, Timişoara, 2003.
[2] Hau E., *Windkraftanlagen.* Springer-Verlag, Berlin – Heidelberg - New York – London – Paris – Tokio, 1988.
[3] Justus C.G., *Winds ans Wind System Performance*, Franklin Institute Press, Philadeplhia, USA, 1978.
[4] Nedelcu D., *Microsoft Excel – Concepte teoretice şi aplicaţii.* Editura Orizonturi Universitare, Timşoara, 2003.
[5] Marteus L.K., *Maşinostroienie* – Tom 12, Moskva, 1949.
[6] Spera D.A., *Wind turbine technology*, ASME Press, New York, USA, 1994.
[7] Vlădea I., *Tratat de termodinamică tehnică şi transmiterea căldurii.* Editura Didactică şi Pedagogică, Bucureşti, 1974.
[8] ***** *Manual Data Logger Meteo 32,* Ediţia 1.4.0, Ammonit, 2005.
[9] ***** *SR 13465,* 2007.
[10] www.wasp.dk
[11] www.windatlas.dk
[12] www.windenergy.com

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