International Conference on Economic Engineering and Manufacturing Systems
Braşov, 25 – 26 October 2007

ON THE STATISTICAL ASPECT OF THE WIND POTENTIAL OF A LAND ZONE

Mariana DELIU, Gheorghe DELIU
"Transilvania" University of Brasov, Romania

Abstract. The paper deals with the data processing method in the case of the evaluation of the wind energy of a land zone. Considering the wind speed as a random variable, the authors use the Weibull's model for estimate the probability of the wind speed to take greater values than the inferior limit of the speed range a wind turbine needs in order to work in good conditions. After the theoretical features are presented, the application is made on a set of wind speed values measured at Sulina and presented by INMH in its web page. The results of present study gives to virtual investors a useful guide to the decision to take about the wind potential of a land zone utilisation.

Keywords: random, wind speed, energy potential, estimation method

1. Introduction

In the present conditions of energetic crisis, the concern to find new unconventional energy sources becomes more than necessary. One of the cheaper sources is *wind energy*, which was used for centuries, but is having a huge development in the last time only.

Wind energy is plentiful, renewable, widely distributed, clean and reduces toxic atmospheric gas emissions when it is used to replace fossil-fuel-derived electricity.

The investment decision of individual users or firms on wind power utilities installation demands an appropriate knowledge of wind potential for every site and/or customer type.

At the present time, although there are some maps of wind velocities in Romania, the authors consider there is no available literature concerning the statistical analysis of this phenomenon. This analysis would be useful in order to estimate the wind energy potential for an enough long time interval, no matter where the wind energy transformer should be placed.

Such researches have a great importance for our country especially, given the small number of wind turbines so far installed, in spite of the proved existence of some zones with a considerable wind energy potential.

From this point of view, it's worthy to note that, while the wind produced electricity accounts for approximately 20% of electricity use in Denmark, 9% in Spain and 7% in Germany [1].

Last, but not least, it's well to know that the global prediction for the installed wind power is of 90 GW in 2007, 107 GW in 2008, 132 GW in 2009 and 160 GW in 2010 [2].

2. Wind speed as a random variable

As we said in a former paper [1], the energy quantity that passes in a second through the unit area placed perpendicular to the wind direction is denominated as *energy flux* density:

$$P = \frac{\rho v^3}{2}, \tag{1}$$

where ρ is the air density and v is the wind speed.

This flux density evidently presents different values in function of time and place. For a given location, we can define the *wind potential of the site* as the mean value of the energy flux density taken on a sufficient long time interval T:

$$\varepsilon = \lim_{T\to\infty} \frac{1}{T}\int_0^T P(t)dt \tag{2}$$

Sometimes, one uses the term *wind potential* for the mean value of the wind energy passing in a year through a unit area placed perpendicular to the wind direction, too:

$$E = \int_0^T P(t)dt, \tag{3}$$

with T = 1 year = 8760 hours.

If we replace P from the equation (1) in (3), we get the expression

$$E = \frac{\rho}{2}\int_0^T v^3(t)\,dt, \tag{4}$$

which shows that the available energy is a function of the third power of the air speed; from this reason the precise determination of both wind speed and duration is very important, for a given site.

Taking into account the random character of the wind, one can take a decision about the opportunity of a wind plant investment in a given place only after a precise evaluation of the wind speed spectrum. This fact means that only after an exact analysis of the statistically determination of the *weighted wind speed* during a relative long time (some months, years), one can made an useful forecast regarding the type, the size and the number of the wind plants profitable to be used.

It is already known that wind turbines have a good efficiency for wind speeds greater than 3 m/s (Savonius type turbines), while the most middle power turbines even need wind speeds greater than 5 m/s (Darrieus or other types).

Starting from the above mentioned reasons, the authors consider that the probability for the wind should blow with a certain speed or more, for at least a part of a given time interval, is the main criterion to be used in the process of decision.

This approach means that taking the wind speed as a random variable v, one have to find the density repartition function $f(v)$ and repartition function $F(v)$, defined as follows:

The $f(v)$ function characterizes the random variable (v) repartition and is defined as the limit of the ratio between the probability that speed takes values within ($v + \Delta v$) interval and the interval magnitude,

$$f(v) = \lim_{\Delta v \to \infty} \frac{P(v < V \le v + \Delta v)}{\Delta v} \tag{5}$$

The repartition function $F(v)$ represents the probability of the random variable (v) to take smaller values than a certain value V

$$F(v) = P(v < V) \tag{6}$$

and, for a wind speed taken as a continuous random variable will be calculated as

$$F(v) = \int_0^V f(v)\, dv \tag{7}$$

As a repartition density function may be used any continuous function which simultaneously fulfils the conditions:

$$1^0. \quad f(v) \ge 0,$$

$$2^0. \quad \int_a^b f(v)\, dv = 1.$$

In order to choose the adequate function for the wind speed values distribution description, the authors suggest to analyse the available data for a given place (land zone), regarding a enough long time interval (one month, one year or many). From understandable reasons, in that follows the authors will present the results of such an approach made on the data measurements extended along a single month.

The studied location is the meteorological station Sulina, where the wind energy potential may be considered as an appreciable one [3].

3. Data statistical processing

For Sulina station (as well as for any other 22 stations) the National Meteorological and Hydrological Institute (INMH) provide the hourly registered wind speed values [4].

Analysing these data for the entire month of August 2007, the found values of the wind speed were within 0 and 15 m/s, while the duration of each different blow intensity were within 2 hours for calm and 127 hours, for 4 m/s, as shown in Table 1.

Table 1. Speeds and durations

Speed v	Duration t	Speed v	Duration t
0	2	8	37
1	14	9	28
2	61	10	33
3	97	11	20
4	127	12	9
5	108	13	7
6	80	14	2
7	71	15	2

The total observation time was 648 hours (not 31 times 24 = 744), because in some moments within that month there was no registered speed.

After grouping these data in 5 intervals of speed magnitude, we can determine the empiric values of the repartition density $f^*(v)$ and of the repartition function $F^*(v)$ corresponding to each interval, using the relations:

$$f_i^* = \frac{r_i}{N \cdot \Delta v} \tag{8}$$

$$F_i^* = \frac{\sum r_i}{N+1} \tag{9}$$

where r_i is the number of hours in which the wind speeds were within the "i" interval, N is the total number of registered speeds (meaning the total number of hourly observations), Δv - speed interval magnitude and $\sum r_i$ - the summed number

of hours in which the wind was blowing with a speed smaller or equal than the maximum speed of "*i*" interval.

Table 2. Data processing

Δv	r_i	f_i^*	F_i^*
$(0 \div 3]$	174	0.083	0.248
$(3 \div 6]$	315	0.15	0.699
$(6 \div 9]$	136	0.065	0.894
$(9 \div 12]$	62	0.029	0.982
$(12 \div 15]$	11	0.0052	0.998

Taking into account that Weibull's distribution is suitable in a great number of practical situations, here we suggest using it as a theoretical distribution of the wind speeds. This choice is also confirmed by the aspect of the curve presented in figure 1.

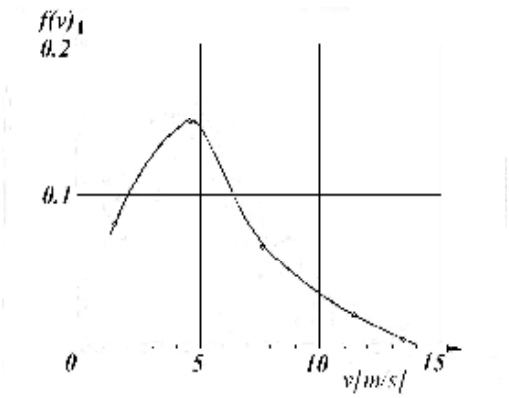

Figure 1. Wind speed density repartition

In this case, the repartition density has the expression

$$f(v)=\frac{\beta}{\eta}\left(\frac{v-\gamma}{\eta}\right)^{\beta-1} e^{-\left(\frac{v-\gamma}{\eta}\right)^{\beta}} \tag{10}$$

while the repartition function expression will be

$$F(v)=1-e^{-\left(\frac{t-\gamma}{\eta}\right)^{\beta}} \tag{11}$$

Here we have denoted: γ - the location parameter, β - the shape parameter and η - scale parameter.

If the values presented in the table 2 are drawn in an Allan Plait [5] grid, they will show as a straight line, which can lead us to the hypothesis $\gamma = 0$, meaning that the theoretical adopted model will become a Weibull biparametric one.

For the data presented in table 2, the graphically estimated parameters are η = 3.8 and β = 1.4. Consequently, the wind speed in the month of August 2007 at the Sulina station was distributed after a Weibull law, for which repartition density has the form

$$f(v)=\frac{1.4}{3.8}\left(\frac{v}{3.8}\right)^{0.4} e^{-\left(\frac{v}{3.8}\right)^{1.4}} \tag{12}$$

while the repartition function has the form

$$F(v)=1-\exp\left[-\left(\frac{v}{3.8}\right)^{1.4}\right] \tag{13}$$

The graphical plots of the empirical repartition function (resulting from measurement data presented in table 2) and of the repartition function calculated with the relation (13) are shown in figure 2.

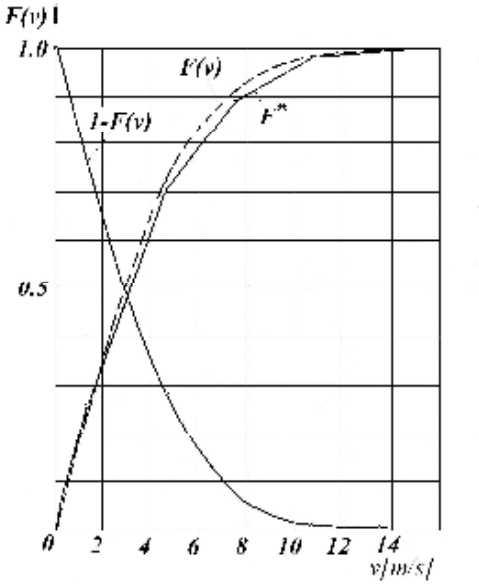

Figure 2. Repartition function

As we can see, there is a good concordance between the results of these two approaches. Indeed, using the Kolmogorov-Smirnov test [6] in order to verify the concordance of the theoretical model with the experimental data, we can find that maximum deviation between $F(v)$ and $F^*(v)$ is

$$\Delta_{\max}=\left|F(4.5)-F^*(4.5)\right|=0.046$$

For a signification limit α = 0.05 and for the sample data volume n = 698, the critical value of the Kolmogorov-Smirnov test is

$$\frac{\lambda}{\sqrt{n}}=\frac{1.36}{\sqrt{698}}=0.051.$$

Therefore Δ_{max} < 0.051, which confirms that

the theoretical model is adequate with the experimental data.

In order to take the decision regarding the opportunity to invest in the construction of a wind turbine in a certain land zone is important to have the possibility to appreciate the weight of wind speeds greater than 3 m/s, or greater than 5 m/s respectively, for an enough long time period.

Simply, this means to calculate

$$P(v > V) = 1 - F(v) \tag{14}$$

So, for our application regarding the Sulina zone, in the month August 2007, we get

$$1 - F(3) = \exp\left[-\left(\frac{3}{3.8} \right)^{1.4} \right] = 0.49 ,$$

$$1 - F(5) = \exp\left[-\left(\frac{5}{3.8} \right)^{1.4} \right] = 0.23 .$$

It means that, in the discussed place and time, the wind was blowing 49% of time with a speed of 3 m/s or greater, respectively 23% of time with a speed of 5 m/s or greater.

4. Conclusions

From the above considerations, we believe that the conclusion regarding the opportunity to make or not an investment in wind turbine must be mainly based on a statistical analysis of the wind energy potential. In this sense, the use of Weibull's distribution for the wind speeds modelling shows itself to be adequate and permits a relative easy emphasis of most decisive parameters for the investment reward. It is to be noted that, for example, more important than the mean wind speed value in a given time interval is the weight of the time in which the wind blows with a greater speed than that is necessary for a good efficiency of a given type of turbine.

Evidently, the study should be based on longer observations of the wind speeds (months, years), but the proposed method and its Weibull model stand also for a greater data amount.

We shall observe also that the speed provided by INMH were measured at the standard height of meteorological stands (2-3 m), while the wind speed is surely greater at the heights about 20 -30 meters, where the horizontal wind turbine axis is generally placed (to say nothing about the turbines placed on the roof of high buildings). But, whatever the turbine's height will be, the presented method and the Weibull model still remain usable.

References

1. *******: http://en.wikipedia.org/wiki/Wind_power. Accessed: 2007-09-20
2. ***: http://en.wikipedia.org/wiki/Image:Wind_2006and prediction_en.png. Accesed: 2007-09-24
3. Deliu, M., Deliu, G.: *A Simple Method to Estimate the Wind Potential of a Region*. **RECENT**, Vol. 8, no. 2(20), July, 2007, p. 91-96, ISSN 1582-0246, Brasov, Romania
4. ***: http://www.inmh.ro. Accesed: 2007-09-03
5. Baron, T., Isaic-Maniu, A., Torissi, L., Niculescu, D., Baron, C., Antonescu, V., Roman, I.: *Quality and Reliability* (*Calitate şi fiabilitate).* Vol. 2, "Tehnică" Publishing House, Bucharest, p. 470-900 (in Romanian)
6. Mihoc, G., Muja, A., Diatcu, E.: *Mathematical Foundations of the Reliability Theory (Bazele matematice ale teoriei fiabilitatii).* "Dacia" Publishing House, Cluj-Napoca, 1976, p. 441 (in Romanian)