Annals of the University of Oradea, Fascicle: Environmental Protection Vol. XXVIII, 2017
Analele Universităţii din Oradea, Fascicula: Protecţia Mediului Vol. XXVIII, 2017

ASSESSING THE PERFORMANCE OF THE WIND TURBINE RELATIVE TO CERTAIN ENVIRONMENTAL PARAMETERS

Dubău Călin*, Cătaş Adriana**

*University of Oradea, Faculty of Environmental Protection, 26 Gen. Magheru St., 410048, Oradea, Romania, e-mail: calin_dubau@yahoo.com
**University of Oradea, Faculty of Sciences, Department of Mathematics and Computer Science, 1 University St., 410087, Oradea, Romania, e-mail: acatas@gmail.com

Abstract

It is well known that the produced and predicted power of the wind turbines depend on various meteorological data and technical data. The result is influenced by the interference of various environmental parameters such like wind speed, air temperature and density, turbulence, precipitation, relative humidity. In the present paper the authors offer a simulation model to study the performance of the wind turbines relative to certain meteorological factors. It will be analyzed the impact of the elevation of the anemometer on the speed profile and the relevance of the average multiannual speed. The assessment of the air density will be also taken into consideration. The obtained results are processed using a MAPLE software program.

Key words: wind turbines, air temperature, wind speed, air density, air pressure

INTRODUCTION

Wind energy is a renewable energy, ecological and sustainable. Wind turbines are energy converters. Kinetic energy will be transformed into mechanical rotational energy which will be converted into electrical power (Gasch, Twele, 2005; Burton, 2001).

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. Active body of aeolian turbines which made the quantity of converted energy is the blade. The achieving of aerodynamic performances, kinematics and energy curves of the aeolian turbines depend on the choice of certain geometry. Energy performance representation that produces a wind turbine, as a whole operating area, is materialized by the characteristic curves that are operating in the optimization process (Dubău, 2005; Dubău, 2004).

There are various types of wind turbines. 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 in a recent paper (Dubău, 2009). A study regarding a vertical turbine V250 can be seen in the paper (Gyulai et al., 2000; Gyulai, Bej, 2000; Gyulai, 2000) and for the horizontal turbine H2500 we can consult the paper (Dubău, 2003). In this context we can also recall the paper (Bej, 2003).

The present paper intends to describe the scientific knowledge in the field of wind turbines in order to select a mathematical model useful in aero-electric aggregates dynamic. It will be estimate the air density over several factors like barometer altitude, placement elevation, and air temperature. The shape of the speed profile curve in the boundary layer is also presented.

MATERIAL AND METHOD

The wind turbine, as a wind energy conversion system, is affected by several technical internal parameters (rotor size, blade shape, electrical connection) and external factors (wind speed, air temperature and density, turbulence, relative humidity and precipitation). In order to convert the power from mechanical to electrical the wind turbine activity depends on power losses like mechanical, electrical and also the copper and iron losses. The mechanical structure which performs this activity is an “aerodynamic engine”. The mathematical model and the physical model as well imply the following components: site offer, the energy exchange at the aerodynamic engine level, optimized geometry of the engine and characteristics curves of the engine in the optimized geometry conditions.

Offer site (emplacement) is a statistics model of the earth’s atmosphere. One associated the speed field parameters, pressures and other parameters of the field at a certain location of the turbine.

All sizes of interested energy are time dependent, being statistically processed in terms of some frequency curves or insurance. The energy exchange at the aerodynamic engine level is based on the interaction forces evaluation between fluid and solid. The mathematical models conceived for characteristics curves of various types of turbines represent the direct information useful for technological design.

Usually the energetically studies are made for quasi stationary regimes. In the case of dynamical studies it cannot be neglected time variation of cinematic sizes. Cinematic power (P_c) associated to some exposed area (S) of the recovery system is

$$P_c = \rho \frac{v^3}{2} S$$

where ρ is mass density.

Some remarks have to be made regarding the wind regime, in order to select the right model which depends on what objectives are targeted during the modeling process.

The terrestrial boundary layer has an extension in terms of hundred of meters. Significance of boundary layer is represented by that zone which is influenced by current friction with solid border of terrestrial surface. Beside of boundary layer, the wind speeds depend on baric gradients and rotation of the earth. Speed profile in the boundary layer depends on ruggedness of the solid border and also on land geometry. Usually, the wind turbine is located in the boundary layer. Therefore, the exposed are of the turbine has different speed. When we work on the energetically model, we use that speed value which is determined at the turbine axis level, this being an approximation. It is accepted for certain modeling.

Wind regime is not stationary. The speed vector depends on time.

Turbulence is a randomly variation of the speed in size and in direction. A lot of aerodynamic phenomena depend on turbulence degree. At the very small speeds the flow can be laminar. Turbulence has a wide spectrum of frequencies.

Gusts are disturbances in speed field caused by vortices generated by terrestrial surface or other disturbances. Strong gusts negatively affect wind turbines in many ways. Trains vortices are periodical movement characterized by determined frequencies. The turbine receives the gust as an aerodynamic shock.

Stability of the atmosphere is also taken into consideration. All in terms of heating of lower layers by contact with the ground which can cause ascending movements and disturb the movement in the horizontal plan of the wind. This phenomenon occurs at huge temperatures and reduces horizontal speeds.

In the present study we propose a mathematical model which allows the evaluation of the horizontal speed mediated in a time interval of minute order. The model is using the method of boxes to which is associated probable frequencies in a large time interval of years order. The box represents a speed interval with a central value and an associated interval.

See below an example of boxes frequent used:

$$0+0,5;\, 1\pm 0,5;\, 2\pm 0,5;\, 3\pm 0,5;\, etc.[m/s].$$

This model identifies statistically the probable frequency curve of speeds boxes. The model does not contain the wide spectrum of turbulence frequency, neither gusts nor stability of the atmosphere. The proposed model is available for an average year within a multiannual year. Regarding the short intervals (month, day, hour) these are sometimes used as fractions of the year.

The elevation of the turbine affects the average speed. For the mathematical model we need the following relations:

$$\frac{v_z}{v_r} = \left(\frac{z}{z_r} \right)^{\alpha}$$

where v_r, z_r are the speed and reference elevation and v_z, z are the speed and elevation of interest. For roughness parameter are used the following values:

– Towns with high buildings	$z_0 = 1,2\ldots3\,m$
– Towns with small buildings	$z_0 = 0,55\,m$
– Suburbs	$z_0 = 0,4\,m$
– Areas with farms and vegetations	$z_0 = 0,3\ldots0,002\,m$.

For the case study we also deal with the extreme values of the speed (these are very rare) which can be calculated by adequate statistic model. These values are necessary for protection measures. There are considerate as maximal (accidental) and determinate by the relation:

$$v_{\max} = k_e \cdot v_m .$$

For high speeds, with a short period, the exponent for the boundary layer is:

$$\alpha = 0,55 \cdot v_r^{-0,77}$$

where v_r is the reference speed at an elevation value of 10 m ($v_r > 20 m/s$).

In terms of energetically analysis, the statistic of speed and air density should be synchronous, and also the size (ρv^3) should be statistically ordered. One determines an average density for a period of time which is introduced in computing relations for a speed domain. Thus, to the average meteorological year, which is identified based on the speed statistic, is associated an average density of the year. The mathematical model, being defined above, has values which can goes up to 10%.

The air density depends on local barometric pressure, temperature and humidity of the air. In computation calculus for the energetically evaluation one can neglect the humidity.

In the aero-energetic interested area can be useful the ideal gas equation:

$$\rho = \frac{p}{RT}$$

- *p*: local barometric pressure P_a;
- *R*: gas constant; R=287 J/kg/^0K;
- *T*: absorbed temperature; $T = \left(273 + t^0C\right)\left[{}^0K\right]$;
- ρ mass density $\left[kg/m^3\right]$.

The barometric pressure at the sea level varies, from meteorological point of view, in the domain $95681 \div 102325{,}3\, P_a$ ($720 \div 770\, torr$). It happens very rare to exceed this domain.

The local barometric pressure depends on the altitude of the location compared with the sea level (the place is considered in the centre of turbine). The relative local pressure (exposure to barometric pressure at the sea level) has the following values as we presented in Table 1:

Table 1

The relative local pressure

Altitude $[m]$	0	200	400	600	800	1000	2000
p / p_{bo}	1	0,976	0,953	0,931	0,909	0,887	0,784

For the comparative calculus we operate with the standard density:

$\rightarrow 1{,}225$ kg/m^3 [altitude: 0; , $p_{bo} = 760\, torr\ \left(1{,}00996 \cdot 10^5\ P_a\right)$, $t = 15^0 C$]

RESULTS AND DISCUSSION

The performance of the wind turbine can be investigated through mathematical models and also verified by experimental measurements.

This paper provides a mathematical simulation, based on the model proposed in the work (Dubău, 2006; Dubău, 2007).

We proceed to investigate the established models and operating applications. In the next case study, from the meteorological stations data one knows the reference information namely:

- the elevation of the anemometer: $z_r = 10m$
- average multiannual speed: $v_{rm} = 5m/s$

In order to establish the terrestrial boundary layer one evaluates the roughness of the land:

$$z_0 = 0{,}3m;$$

$$v_{zm} = v_{rm} \cdot \left(\frac{z}{10}\right)^{\alpha};$$

$$\alpha = \left(\frac{z}{10}\right)^{0,2} \cdot \left(1 - 0{,}55 \lg v_{rm}\right) \qquad (1.1)$$

$$\alpha = 0{,}496 \cdot 0{,}616 = 0{,}305.$$

Considering certain interested values for elevation, we get the following data for the speed in the terrestrial boundary layer, centralized in Table 2 and obtained by making use of the relations above.

Table 2

Speed values distribution in the terrestrial boundary layer

$z[m]$	10	20	30	40	50
$v_{zm}[m/s]$	5	6,18	6,99	7,63	8,17

For the v_{zm} as a continuous function of elevation, one obtains the speed curve distribution in the terrestrial boundary layer shown in Figure 1. The mathematical simulation was studied using a MAPLE software program.

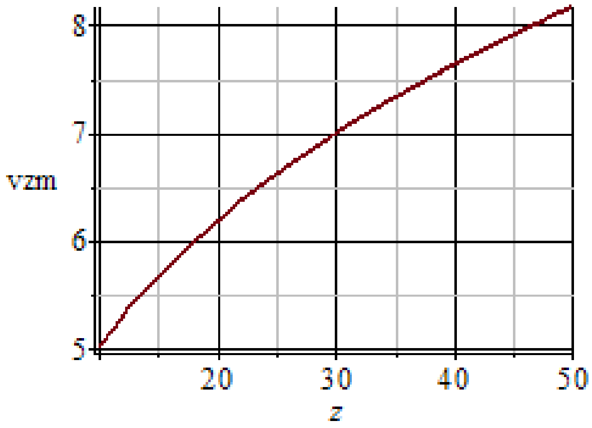

Fig. 1. Speed curve distribution

The next step in our work has to do with the evaluation of the speed profile at the boundary layer for maximum reference speed. In this sense we have to select the maximum speed calculated at the average reference speed namely 5 *m/s,* for the elevation value which is 10 *m*. In the Table 3 are posted several maximum speeds which occur once a few years.

Table 3

Extreme speed values

An appearance at	30 years	50 years	100 years
k_e	8,7	9,2	10
$v_{MAX}[m/s]$	43,5	46	50

Taking for the maximum speed the level $v_{MAX} = 50 m/s$, we deduce from (1.1) that $\alpha = 0,027$. With these values can be determined the distribution of the speed profile in the boundary layer at the maximum reference speed according to the Table 4. The computing relation is $v_{\max} = k_e \cdot v_m$.

Table 4

Speed profile at the maximum reference speed

$z[m]$	10	20	30	40	50
$v_{MAX}\ [m/s]$	50	50,9	51,5	51,9	52,2

CONCLUSIONS

Meteorological data are analyzed and conclusions are deduced for the use of wind turbines under certain conditions. In this model it is clear that the meteorological parameter mentioned above are a big influence on decreased the power production, in addition to the wind speed.

At any modeling, with energetic goal, is required to take into consideration the emplacement (site offer).

The frequency curve of the wind speed influences the technological design characteristic which has to be centered on the speed field. We have operated at the choice of technology with the following values offered by the emplacement. We have to take into consideration the following aspects. The average speed or that of maximum frequency requires the place of maximum emplacement efficiency. The high speeds of the wind with assurances of few hours per year, define the powers and the installation speed of technology. The installation speed can be two or three times bigger then the value of average speed. Accidental high speeds (an appearance once at 30 years, 50 or 100 years) require protection measures of recovery technology.

The air density influences the performances of technology. If in a prospect of the wind aggregate it is offered a power curve function of wind speed, then that prospect need to specify the air density considered by the bidder.

The buyer has to recalculate this curve for air density corresponding to emplacement in which it will be installed the aggregate.

REFERENCES

1. Bej A., 2003, Wind Turbines. Timişoara Polytechnic Press, ISBN 973-625-098-9, Timişoara, Romania
2. Burton T., 2001, Wind Energy Handbook. John Wiley & Sons, LTD, New York

3. Dubău C., 2003, Study on the usage, storage and technical and economic performance of wind-systems. Collaboration in the Research Center in Aero-Energetical systems of the Faculty of Mechanical of the University Politehnica, Bucharest
4. Dubău C., 2004, Valorization of wind power. Annals of University of Oradea, Fascicle of Environmental Protection, ISSN 1224-6255, Vol. IX, Year 9. (In Romanian)
5. Dubău C., 2005, Modern methods regarding the determination of the functioning characteristic curve for a pipe-line network. Annals of University of Oradea, Construcții și Instalații Hidroedilitare Fascicle, ISSN 1454-4067, vol. VIII. (In Romanian)
6. Dubău, C., 2007, The Utilization of Micro-Wind Assemblies within Complex Systems. Timişoara Polytechnic Press, ISBN 978-973-625-408-6, Timişoara (In Romanian, Ph. D. thesis)
7. Gasch R., Twele J., 2005, Windkraftanlagen; Grundlagen, Entwurf, Planung und Betrieb. 5th ed., Teubner.
8. Gyulai F., 2000, Contributions on horizontal axis wind turbine theory. Proceedings of the 5th International Conference on Hydraulic Machinery and Hydrodynamic, Oct. 2000, Timişoara, Romania
9. Gyulai F., Bej A., 2000, State of Wind Turbines in the End of 20th Century and Proposals for Romanian Options. Buletinul Ştiinţific al Universităţii „Politehnica„ Timişoara, Romania, Tom 45(59), ISSN 1224-6077
10. Gyulai F., Bej A., Hentea, T., 2000, Contribution to aerodynamic optimization of horizontal axis wind turbines for mountain sites. ENERGEX’2000, Proceedings of the 8th International Energy Forum and the Conference of the International Energy Foundation, Las Vegas, USA