A WIND POWER ANALYSIS APPLIED TO THE SOUTH COAST OF BRAZIL

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Abstract. *In the present work a study of the wind energy potential from the EMA (Estação Marinha de Aquacultura) region, located at FURG, Querência, in the city of Rio Grande was made. Since there were only three months of data obtained from a local station, available data from a wind speed measurement station, located at 15 km far from the interest place were used. In order to contour this obstacle, an adequate method to convert the data from a near weather meteorological station was used. For the wind energy potential analysis, a Weibull Distribution and the Wieringa method for the correction of the velocity, were used.*

Keywords: *wind power, wind turbine, Wieringa method*

1. INTRODUCTION

In now-a-days world, the energy has becoming one of the most valuable profits for the humanity. Almost all man's activities are associated with at least one kind of energy. Since the majority of the used energy is obtained from product and/or process which will probably become exhausted with time, it is an important issue to have the energy matrix based not only on no renewable resource, but also include to the present energy matrix some renewable sources, reducing in this way, the consumption of the available no renewable energy resources. In this context, the available energy that can be obtained from the airflow in the low atmosphere has become and important reinforcement to the present days energy supply. In general, the electrical converted form of this energy source is used.

To take the maximum advantages of the available wind energy, it is necessary a complete understanding of the wind behavior in the region where the equipment (aerogenerator) will be installed. This knowledge should be obtained from wind velocity and direction data and compiled to the interesting region. In many cases, the available data does not have sufficient information to supply this necessity. In this case, using an adequate data conversion method, it is possible to use the data obtained from regions in the proximities of the interest area to complete the study. In this work, the Wieringa method (Wieringa, 1976) was used in the conversion of the wind data obtained inside the FURG campus, at the city of Rio Grande, a region close to the south coast of the Rio Grande do Sul, to the region of Cassino Beach, in the district of Querência, also located at Rio Grande city, but 15 km far from de first place. With this data procedure, it was possible to estimate the wind power density of the interest region, and consequently determine the possible amount of energy which will be provided by an aerogenerator that will be installed in the Estação Marinha de Aquacultura of the Universidade Federal do Rio Grande - FURG.

An important wind potential is observed in the energy Atlas of the region in study, therefore in order to guarantee the economic viability of a wind power energy generation, a more detailed study should be performed, and a wind velocity and direction should be obtained in the region of the installation of the aerogenerator. An annual average wind potential for the region will allow a better estimation of the real available energy resource.

The regions of plain coasts like the south region of Rio Grande do Sul, where a reduced number of obstacles and low turbulence in the wind flow are observed, are more suitable for the good use of the available wind energy of the region. In this kind of regions, higher velocities of the wind may be observed in the proximities of the ground, which is very favorable condition for the installation of wind turbines.

2. WIND POTENTIAL FORMULATION

The available wind power that can be converted by a turbine is the kinetic wind energy per unity time that passes through a turbine rotor blade with velocity V. This power is proportional to the cube of the wind velocity and given by Eq. (1).

$$P_o = \frac{1}{2}(\rho A V)V^2 = \frac{1}{2}\rho A V^3 \tag{1}$$

where A is the cross section area of the rotor blade, ρ is the density of the air and V is the instantaneous wind velocity.

Equation (1) represents the theoretical available wind energy (power). Since the air must be able to flow throughout the turbine, only part of this energy may be converted in mechanical energy with the wind rotor. According to Betz

(Dunn, 1986), the ideal (maximum) wind turbine capacity factor is 59.3%. Actually, values between 20 and 30% are obtained with the commercial turbines.

The wind velocity V is not constant. It varies with the climatological conditions along the time and analytical expressions for the characterization of the wind behavior along time (years) are normally used for the determination (estimation) of the available wind potential of a specific region. The usual procedure is to determine a probability distribution function of the wind velocity based on a measured wind velocity and direction data. The measures must be performed as near as possible of the region where the turbine will be installed. This analytical technique offers a consistent tool for the extrapolation of measured data, which allows the data to be used in a different place of that they where originally obtained. Moreover, combining the mathematical description of the wind frequency with the turbine power curve it is possible to determine the total energy that can be generated along the year. Thus, with the wind speed probability distribution, the available wind power of a specific region may be determined by the wind speedy probability density function given by Eq.(2):

$$P = \frac{1}{2}\rho\, E(V^3) \tag{2}$$

where $E(V^3)$ is the mean of the speed cubed.

If both $E(V^3)$ and ρ (air density at ambient temperature) are taken in the SI unity system, (m^3/s^3 and kg/m^3, respectively) the probability density function will be given in W/m^2.

3. MEASURED DATA

The data used in the wind power density evaluation where obtained from the *Automatic Weather Meteorological Station* - A802 located in the university (FURG) campus at (32°04'43"S and 52°10'03"W), for a period of one year and from another station placed in the Estação Marinha de Aquacultura - EMA (32°12'20"S and 52°10'42"W) for a period of three months. The data was measured using a cup-type anemometer and directional sensors placed at 10 meter from the ground. The obtained data are: average velocity, maximum velocity and average direction. The data was taken in the last ten minutes of each hour.

4. POWER DENSITY DETERMINATION

The objective of this work is to determine the wind power density at 12 meter from the ground for the location where the EMA station is placed. In this place a 7,5 kW wind turbine will be installed. As there were few wind dataset available for this site (three months), the solution was to use the data obtained from the A802 station, using an adequate method for corrections.

In this way, from an available dataset measured in a determinate location, it is possible to perform a data correction in order to allow the use of this dataset for the determination of the power density potential in a region different from that where the data was obtained. The Wieringa gust factor method (Wieringa, 1976) and a logarithmic vertical velocity distribution correction were used to achieve this data correction.

In the Wieringa method, the shelter effects caused by small-scale obstacles are removed from the velocity dataset. The method may be applied to a dataset without any kind of information about the surroundings locations and without needing reference stations. Actually, the information about the shelter effects will be "extracted" from the available wind dataset.

From a dataset with known average wind velocity and gust factor, it is possible, with the Wieringa method, to determine the roughness lengths (as function of the azimuthal angle) of a wind station.

The Wieringa method considers that the influence of the roughness length to the wind velocity occurs only in a small region near the ground. Above this region, the wind velocity becomes independent of roughness effect. According to Wieringa (1976), for regions with roughness length between 20 and 30 m, the height of non-influence on the velocity profile should be 60 m. It is also necessary to consider that for winds with velocity above 6 m/s, the velocity distribution has a Gaussian behavior around the mean. Assuming a logarithmic distribution for the wind velocity profile, it was derived an expression to correlate the wind velocity from a wind station (V_s) to the location where the aerogenerator will be installed (V_r). This expression also includes the roughness factors and is given by Eq. (3).

$$V_s = V_r \frac{\ln\left({z_b}/{z_{or}} \right) \ln\left({z_s}/{z_{os}} \right)}{\ln\left({z_r}/{z_{or}} \right) \ln\left({z_b}/{z_{os}} \right)} \tag{3}$$

where z_b is the non influence height (60 m), z_r is the height of the wind station anemometer, z_s is the height of the searched velocity, z_{or} is roughness factor of the wind station and z_{os} is the roughness factor of the region of the searched velocity.

The use of Eq. (3) requires the determination of the roughness factors for the wind turbine location. At the point where the wind potential will be evaluate (EMA location) the sectors division were based on the Menna and Perceval (2004) and its surroundings was divided in 4 sections with similar obstacles. This division is shown in Fig. (1). The north is set as 0° and the angle increases clockwise. The sectors limits where determined with a compass, thus it was necessary to perform a magnetic declination correction.

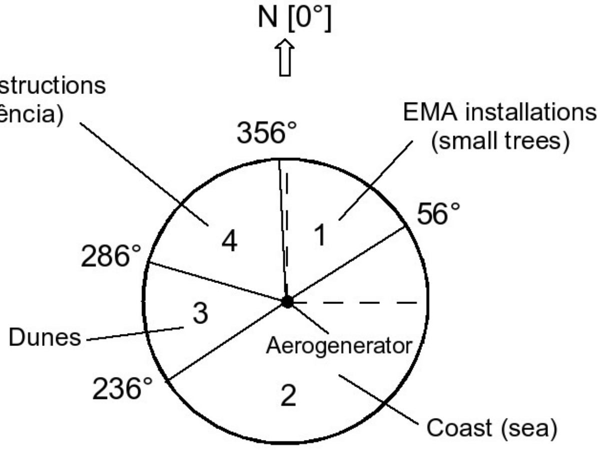

Figure 1. Sectors division for the EMA location (with magnetic declination correction)

Using the sectors division for the EMA station and the Wieringa method, the roughness length is calculated with Eq.(4) (Wieringa, 1976).

$$\ln Z_{0s} = \ln Z_s - \frac{E}{\langle G \rangle - 1} \tag{4}$$

where Z_{os} is the roughness length for each sector; Z_s, the anemometer high (10 m); E is the skewness for gust factors. (E=1,96) and $\langle G \rangle$ is the median value of gust factors.

$$G = \frac{V_{raj}}{V}$$

V_{raj} is the wind gust velocity and $V = V_s$ is the wind velocity in the same measurement interval .

In this way, the roughness length is calculated for EMA station using the Eq. (4) and the dataset for the months between June and August 2005. These results are presented in Tab.(1).

Table 1. Roughness length calculated for each sector at EMA station

Sector	1	2	3	4
Z_{or} (m)	1.07	0.16	0.70	1.02

Solving Eq.(3) using roughness length from Tab.(1), it was found the corrected velocities for EMA station at 12 m. Correlationing these velocities with the A802 data for the months June to August 2005, it’s possible to found a correlation function between the velocities data from A802 and EMA station at 12 m. This function will be used for correct the wind speed to the other months of the year.

The correlation function found is shown in Fig.(2).

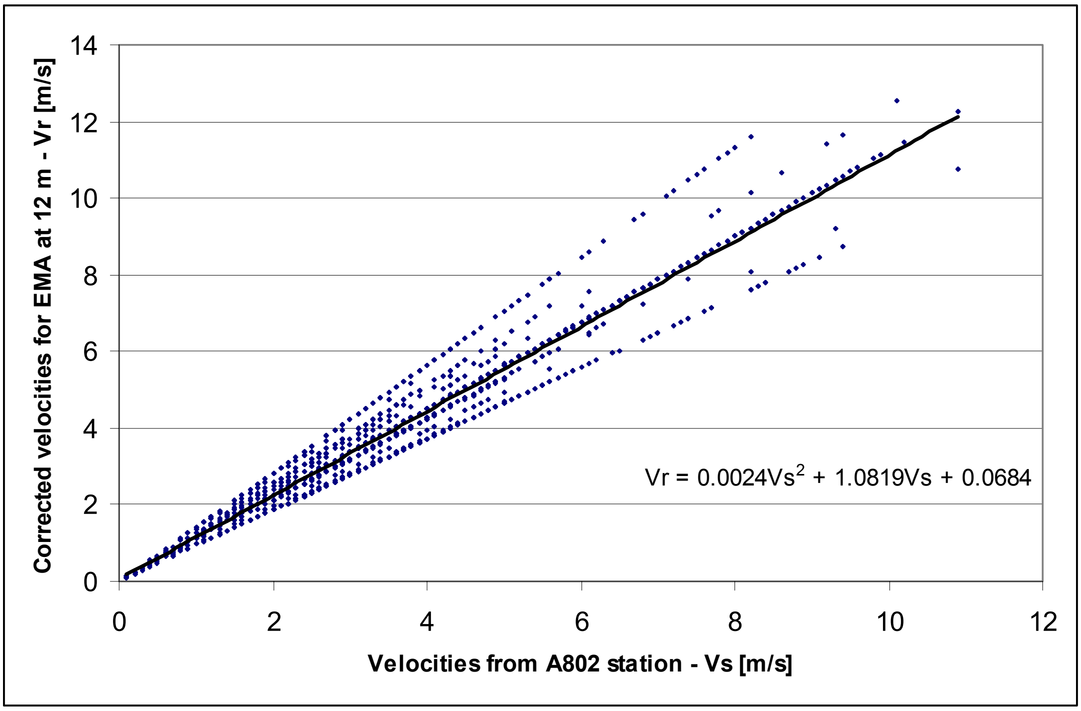

Figure 2. Velocity correlation Vr (EMA) x Vs (A802) – June to August 2005.

Equation (5) is then used to convert the data obtained from A802 station for EMA station at 12 m elevation.

$$V_r = 0.0024V_s^{\ 2} + 1.0819V_s + 0.0684 \quad (5)$$

From Fig. (2), we conclude, that actually there are four different corrections to be made, depending on each sector. In this figure, every straight line represents a different sector that does not start or end equally with the A802, but coincided in time and direction. So, the data were separated in these new sectors that start and ends simultaneously, and new corrections were made, without using the velocity correlation equation. Just the mean correlation function was used because the results using one function for each sector or using the mean correlation function presented an error minor than 5%.

After, the mean correlation function (Eq.5) can be applied for the all dataset from A802. Table (2) presents the mean velocities and the standard deviation calculated for EMA station at 12 m for each month.

Table 2. Mean corrected wind speed and standard deviation for EMA station

Month	Year	Corrected Wind Speed EMA [12m] V_r [m/s]	Standard Deviation [m/s]
June	2005	3.89	2.11
July	2005	4.14	2.04
August	2005	4.40	1.69
September	2005	6.49	2.81
October	2005	5.55	2.56
November	2005	5.28	2.09
December	2005	5.58	2.48
January	2006	4.91	2.07
February	2006	4.93	2.19
March	2006	5.19	2.24
April	2006	4.37	2.15
May	2006	4.43	2.08

According Lopes (2002) the Weibull distribution is a probability distribution adequate for characterize the wind behavior in the studied region.

The Weibull distribution is a semi-empirical expression proposed by Ernest Hjalmar Walladi Weibull at 1939. It is expressed by Eq. (6).

$$f_X(x) = \left(\frac{c}{b}\right)\left(\frac{x}{b}\right)^{c-1} e^{-(x/b)^c} \tag{6}$$

where f_x (x) is a probability density function. being (x) the wind corrected velocity; c is the shape parameter and b is the scale parameter.

The shape parameter. according Koeppl (1982). can be calculated using Eq. (7).

$$c = \left(\sigma/\mu\right)^{-1.086} \tag{7}$$

where σ is the standard deviation and μ is the mean wind speed.

According Newland (1993) the Weibull distribution has mean and standard deviation in terms of gamma functions. In this way. the scale parameter. can be calculated as:

$$b = \frac{\mu}{\Gamma\left(1+\frac{1}{c}\right)} \tag{8}$$

The mean of the speed cubed can be determinate by the Eq. (9). according Hennessey (1977).

$$E\left(V^3\right) = a^{-3/c}\,\Gamma\left(1+3/c\right) \tag{9}$$

From the corrected velocities data. the meam value and the standard deviation results.

$\mu = 4.93$ m/s

$\sigma = 2.34$ m/s

Aplying these values in Eq.(7) and (8). the shape and scale parameters are calculated.

c = 2.25

b = 5.57 m/s

Finally. the mean of the speed cubed. is calculated using Eq. (9).

$E(V^3) = 205.29\ m^3/s^3$

Considering the mean air density with 1.22 kg/m^3. the wind power density is calculated. using Eq. (2):

$P = 125.23\ W/m^2$

5. CONCLUSIONS

In this work the wind power analysis applied to the south coast of Brazil was made. A dataset obtained from the *Automatic Weather Meteorological Station* - A802, located in the university campus of FURG, was corrected using the Wieringa method, in order to evaluate the wind resource at Estação Marinha de Aquacultura – EMA, where will be installed a wind turbine. The Weibull probability distribution was used in the calculus of the wind power density, and the power density calculated for 12 m above de ground was 125.23 W/m^2. This calculus is the first step for the Technical and Economic Viability Study. After this, several turbines will be simulated in order to select what turbine can generate more energy from this available potential.

6. ACKNOWLEDGEMENTS

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