VI CONGRESSO NACIONAL DE ENGENHARIA MECÂNICA
VI NATIONAL CONGRESS OF MECHANICAL ENGINEERING
18 a 21 de agosto de 2010 – Campina Grande – Paraíba - Brasil
August 18 – 21, 2010 – Campina Grande – Paraíba – Brazil

Wind characterization and wind power potential assessment from Triunfo-PE in Brazilian northeast region

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Resumo: *The wind characterization in terms of wind speed, direction and power is the first step to obtain the initial feasibility of generating electricity from wind power through a wind farm, in a given region. To archive a robust wind characterization booth quantity (long time series from wind data's, frequency and quantity of data's, etc) and quality (reliability of the wind measurement values, height of wind speed data acquisition, etc) of the wind data must be optimize to support an accurate statistical study. The Weibull distribution is widely used to characterize the nature of the wind distribution, from Weibull analyze the wind speed probability distribution function f (V) with its respective shape (K) and scale (A) parameters, which define the pattern for the winds of a given region, is obtained. This paper aims to present the winds characterizations and its power potential, from Triunfo, situated in Pernambuco state in the Brazilian northeast region. The wind data's were obtained from SONDA (Sistema de Organização Nacional de Dados Ambientais) project meteor station (wind speed, wind direction and temperature) at height of 50m during 30 months. The Triunfo wind's characterization and wind power potential assessment study shows a average wind speed (V) of 11,27 m / s, predominant Southeast wind direction, average wind power density (P) of 1.672 W/m^2 and Weibull parameters shape (K) and scale (A) equal to 2,0 and 12,7 m/s respectively. Those values, demonstrate an important wind potential in this region for future wind farm prospection's.*

Palavras-chave: *Wind speed, Wind energy, Weibull, Brazil, Triunfo, Wind resources*

1. INTRODUCTION

Wind energy is one of the most usage forms of renewable energy, according (GWEC,2008), in 2008 the world celebrate the 100GW mark in total installed wind energy capacity, in this scenery, USA (20,8%), German (19,8%) ,Spain (13,9%), China (10,1%) and India (8,0%) are the top five countries in wind energy capacity installed, in another hand USA (30,8%), China (23,3%), India (6,7%), Germany (6,2%) and Spain (5,9%) were the top five countries in new wind resources system installed in 2008 year. Booths Chinese and Indian improvements in wind energy sector are remarkable, deep analyze about current and future wind energy scenery in China is present by Changliang and Zhanfeng (2009).

The petrol barrel price increase (up to 150$/barrel in the middle of 2008), the free CO_2 energy process, matured and reliable technology and the countries energy politics (internal economical supporting and minimal energy purchasing price during an agreed time) are the more significant factors that contributing to increase the total amount of wind energy installed.

Brazil has a total of 104,7 GW (ANEEL,2009) of installed power, 68,9% of this amount (energy matrix), comes from hydraulic resources and only 0,37% (414.000kW) from wind energy resources. The first Brazilian wind atlas, published by the Electric Power Research Centre – CEPEL/ELETROBRAS in 2001 shows that the potential for onshore wind energy capacity is 143 GW in Brazil (at 50 meters high) and the best wind resources in terms of wind speed and capacity factor are in the Northeast, Southeast and Southern Regions (Camargo et al,2002).

In order to stimulate new wind power projects, PROINFA was established by the Brazilian Congress as a two-phase, long-term program. In the first phase, 1.422.92 MW of wind farm projects have been already selected and awarded the 20-year Power Purchase Agreement through ELETROBRAS. The selection bidding process required some of the main pre-requisites for financing the projects: environmental licenses, qualified wind measurements, land clearance through lease or property ownership, etc. The 20 year power purchase contracts with ELETROBRAS have energy prices ranging from €77 to €87/MWh (equivalent to R$212 to R$241/MWh) in March 2007, depending on the capacity factor of the project. In PROINFA's first phase (PROINFA I), as of December 2006, 208,3MW of wind energy projects are commissioned (159 MW in South, 49.3MW in Northeast Brazil) (Bueno et al, 2008)

2. THE WIND CHARACTERIZATION AND POTENTIAL ASSESSMENT REVIEW

The wind characterization in terms of speed, direction and wind power is the first step to obtain the initial feasibility of generating electricity from wind power through a wind farm, in a given region. In the wind energy literature, many relevant works have been developed in this aim. Rio et al (2006) studied monthly forecasts of the average wind speed in Portugal and Cadenas et Rivera (2002) in the south coast of Oaxaca – Mexico using the Autoregressive Integrated Moving Average (ARIMA) and Artificial Neural Networks (ANN) methodologies for the treatment of wind time series. Serrano et al (2007) analyze the wind characteristic and energy potential at Cucuta- Colombia presenting the Weibull characteristics parameters for the wind of this region and also and simulation of wind generation with an wind turbine of 1,5MW in 3 different heights, Kose et al (2004) and Ucar and Balo (2009) investigate the wind characteristics and energy potential in Kutahya and Uludag-Bursa respectively, booth in Turkey, Ahmed et al (2006) and similar work in Pakistan to verify the possible use of wind energy for irrigation deep well pumping and small scale power generation , Zhou et al (2006) in the Pearl River Delta region in China and Elamouria and Ben Amar (20089 in Tunisia. Chang et al (2003) present an assessment of wind characteristics and wind turbine characteristics in Taiwan and Fawzi and Jowder (2009) did a similar study in the Kingdom of Bahrain utilizing the graphical method and Weibull for the wind statistical study. Bekele and Palm (2009) present and study the wind energy potential assessment at four typical locations in Ethiopia and Raichle and Carson (2008) in the Southern Appalachian Ridges in the Southeastern United States including and estimation of annual energy outputs from a small wind farm, Solorzano and Bernat, (2009) developed and deep statistical analysis of wind power in the region of Veracruz (Mexico) and Cellura (2008) et al did an similar statistical analysis for wind speed spatial estimation in Sicily. Omer (2008) review the wind energy resources of Sudan and its application for water pump and Silva et (2008) al describe the Wind power in the predominant wind direction in Northeast Brazil

3. TRIUNFO REGION

Triunfo (07º50'17" S, 38°06'06"W , average elevation of 1.004 m) is a city of Pernambuco state, in the arid Sertao region in Northeastern Brazil. Situated between mountains and at a lakefront, the city has a semi arid - hot and dries climatology with annual average temperature around 20.4 °C, the population in 2008 was 15.724 and the area is 191,52 km² (IBGE,2009). Regarding the economical aspects, the main economic activities in Triunfo are based in commerce and agribusiness, especially creation of goats, cattle, sheep's, and plantations of guavas and sugarcane. The Human Development Index (HDI) of Triunfo is 0,714 in comparison of 0,800 of Brazilian average.

4. METEOROLOGICAL DATA'S – SONDA PROJECT

Triunfo is one of the Brazilians cities who have a SONDA project base. The SONDA "Sistema de Organização Nacional de Dados Ambientais para o setor de energia" (Brazilian Depository System of Environmental Data for the energy sector) project is chiefly linked to the climatic area but is strongly oriented towards providing adequate support to activities in the area of renewable energy, chiefly in the assessment of the solar and wind energy resources (Ortega et Ulgiati, 2004).

The wind data's used in this project is obtained from SONDA project; the wind speed, direction and temperature were taken at height of 50m at each 10 minutes and validate according SONDA quality project procedures, to assure its reliability. A total of 30 months of measurements between 2004 and 2007 in Triunfo meteor station (07° 49' 38" S, 38° 07' 20" and altitude of 1.123m), were use in the current study. The table below describes the months and years used in the study.

Table 1. Months of wind data's collected measurements used in the current study

Month	Year			
	2004	2005	2006	2007
January		X	X	X
February		X	X	X
March		X	X	X
April		X	X	X
May		X	X	
June	X	X	X	
July	X	X	X	
August	X		X	
September	X		X	
October	X		X	
November	X		X	

December	X		x	

5. STATISTICAL DISTRIBUTION FOR WIND DATA

The Weibull law is the most frequently used model to describe the distribution of the wind speed (Takle e Brown, 1977 ; Nielsen et al, 1994). The distribution is also used in others sectors like automotive sector for analysis of survival data (Lima,2006)

The probability density function (PDF) of the wind speed is given by:

$$f(V)=\left(\frac{K}{A}\right)\left(\frac{V}{A}\right)^{K-1}\exp\left(-\frac{V}{A}\right)^{K} \tag{1}$$

Where:

- f(v) is the probability density function of the wind speed;
- A is the Weibull scale parameter;
- K is the dimensionless Weibull shape parameter

According the value of K, the Weibull distribution is similar to others kind of statistical distribution (k = 1,0: exponential, k = 2,0: Rayleigh, k = 3,5: Normal) (Duarte, 2004)

The cumulative distribution function F (V) is writing as follow:

$$F(V)=1-\exp(\left(-\frac{V}{A}\right)^{K} \tag{2}$$

The wind power available P (W) that can be obtain in cross sectional area A_T (circular area create by the wind turbine blades) perpendicular to the wind at speed V(m/s) with an given air density ρ (Kg/m^3) , is done by the follow equation:

$$P=\frac{1}{2}.\rho_{air}.A_T.V^3 \tag{3}$$

The amount of power which can be extracted from the wind depends on the available wind energy and on the operating characteristics of the wind energy extraction device (Omer, 2008). However, wind machines cannot use 100% of this power due to the Berz limit. The previous equation (3) can be rewrite adding a coefficient, called Cp, which defined the maximum efficiency of the Betz limit (0.593)

$$P=\frac{1}{2}.C_P.\rho_{air}.A_T.V^3 \tag{4}$$

6. QUALITY OF DATA

The wind data obtained from SONDA project (see more details in topic 4), were analyzed using the WAsP program. WAsP is a PC program, developed and distributed by the Wind Energy Division at Risø DTU, Denmark, for predicting wind climates, wind resources and power productions from wind turbines and wind farms. The predictions are based on wind data measured at stations in the same region; the program includes a complex terrain flow model, a roughness change model and a model for sheltering obstacles.

Firstly, the date was minusciolis analyzed, and only corrects wind speed; direction and temperature were used to improve de data's reliability. The SONDA project has itself data qualification process, adopted the criteria of analysis established by the Webmet.com.

The process of quality control consists of four sequential stages initiated with coarser filters and finished with more filters refined. These filters are a given point is considered approved or suspected of impropriety by implementing algorithms that adopt the following criteria:

- Phase 1➔Algorithm 1: Signals the value as when physically impossible suspicion
- Phase 2➔Algorithm 2: Signals the value as a suspect when the event is extremely rare

- Phase 3➔Algorithm 3: Flags value as a suspect when inconsistent with measures presented by other variables in the same season or when it presents temporal variations not consistent with that expected for the variable
- Phase 4➔Algorithm 4: Signals the value as a suspect if the measure is inconsistent when compared with estimates of computational models.

The approval at each step is a requirement for continuing the process. Thus, only when a data is considered approved on a stage, the next step begins. If no approval, the process stops and the data will receive the equivalent code to the suspect. If approved, the data will receive the code approved and the next step will be initiated, as explained below.

7. RESULTS AND DISCUSSION

The Fig 1, show the wind speed profile (monthly average) from Triunfo meteor station, the maximum value of wind speed is observed in July / 05 (21,9 m/s) and the minimum value in March /05 (6,86m/s). The final mean wind speed is 11, 83 m/s and the wind mean speed from the derived Weibull distribution is 11,27m/s , with 4,72% of discrepancy in comparison with the mean wind speed from data.

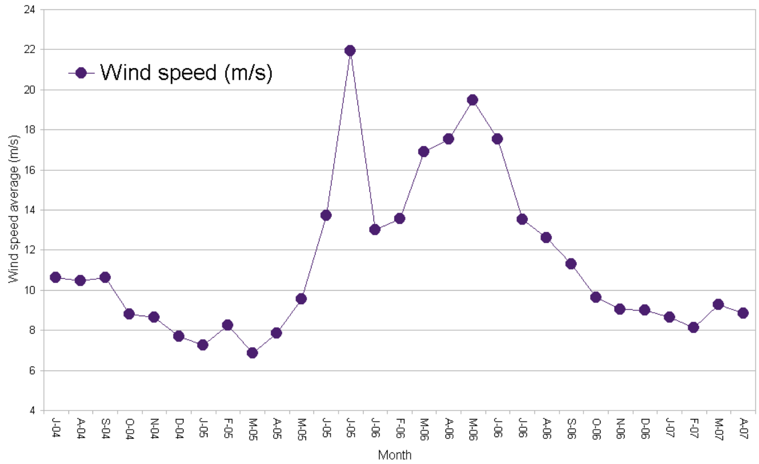

Figure. 1. Monthly wind speed average @ 50m from Triunfo meteor station

The temperature wind profile @ 50m, in Triunfo meteor station is represented in the Fig 2. The highest wind temperature is detected in Dec-04 (22,31 ºC) at Summer time (south hemisphere) and the lowest in Jun-05 (17,11 ºC) winter time (south hemisphere) with average of 20,20 ºC during the studied period.

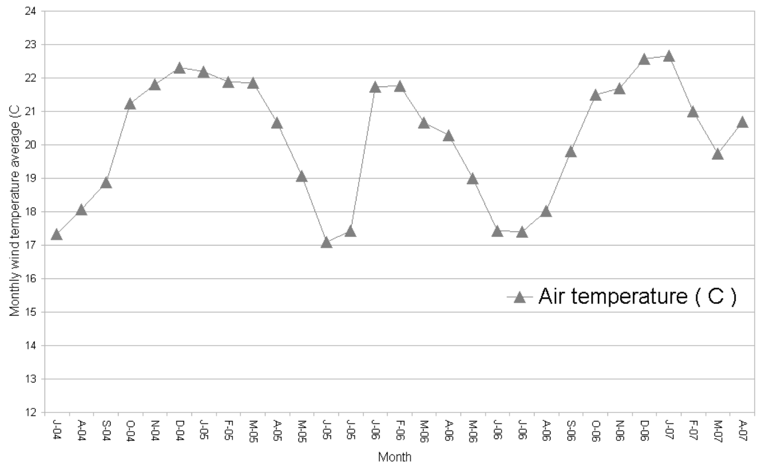

Figure. 2. Monthly wind temperature average @ 50m from Triunfo meteor station

Regarding the wind direction, Triunfo region has southeast predominant wind direction, as showed in the wind rose in Fig. 3. The expressive wind direction of Triunfo is very beneficial to wind energy prospection, because the amount of energy lost in the wind turbines due to the wind direction changes is reduced.

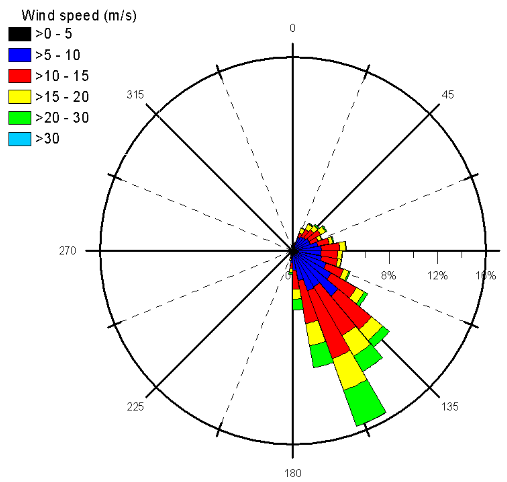

Figure. 3. Triunfo meteor station wind rose @ 50m

Using the Weibull distribution (1), we obtain the scale (A) and shape (K) parameter for each month (monthly average). The Fig. 4, represents the distribution of booths parameters during the studied time period.

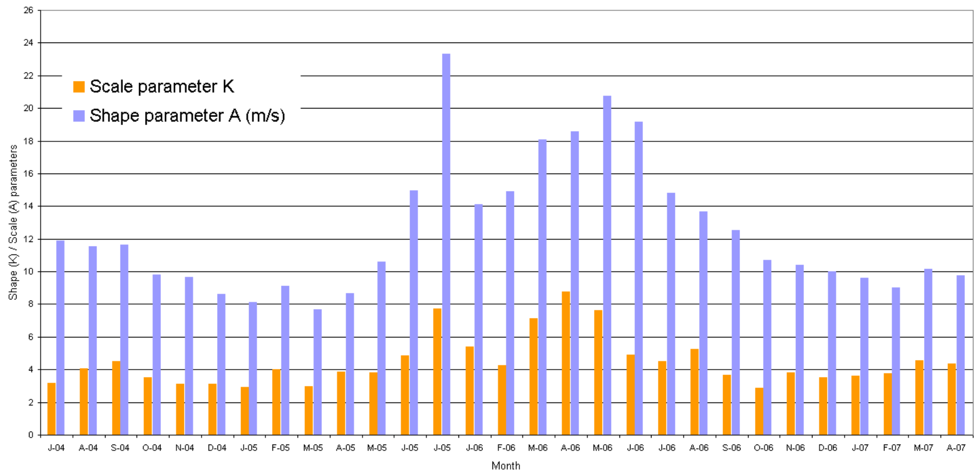

Figure. 4. Monthly shape (K) and scale (A) Weibull parameter average @ 50m from Triunfo meteor station

From WAsP analyze , the final values of K and A parameters are 2,0 and 12,7m/s respectively. Due to the fact that the K parameters equal to 2,0, the Rayleigh distribution can also be used to characterize the wind distribution in the studied zone. The Weibull scale parameter (A) is common related to the wind speed average. Fig.6 shows the correlation between the wind average speed (V) and scale parameter (A). In this study, the value of Weibull scale parameter is higher than the wind speed value in the order of 5% up to 15%. The wind power by useful area P (W/m^2) monthly average estimation is obtain from (3).

The WAsP program uses a constant air density value (1,225kg/m^3) in order to calculate the mean power density. This approach facility the final calculation of wind assessment because it does not correlate the wind power calculation with the influence of air temperature and altitude values. In regions with hot climate, as the Brazilian northeast and in special Triunfo, who has associated with this climate an important altitude (1.004m overseas in average) the impact of temperature and altitude in the air density is important an must be take in consideration during the wind power calculation.. Fig. 5 represents the two power density curves, one with air density constant and equal @ 1,225kg/m^3 and another with the air density value calculated according the base altitude1040m and the monthly air average temperature. The values of power density with constant density are slightly higher, in average and 16%. The mean power density from data using WAsP is calculated as 1.671W/m^2 and the mean power density derived from Weibull is 1.672,3 W /m^2 with a 0, 14% of discrepancy.

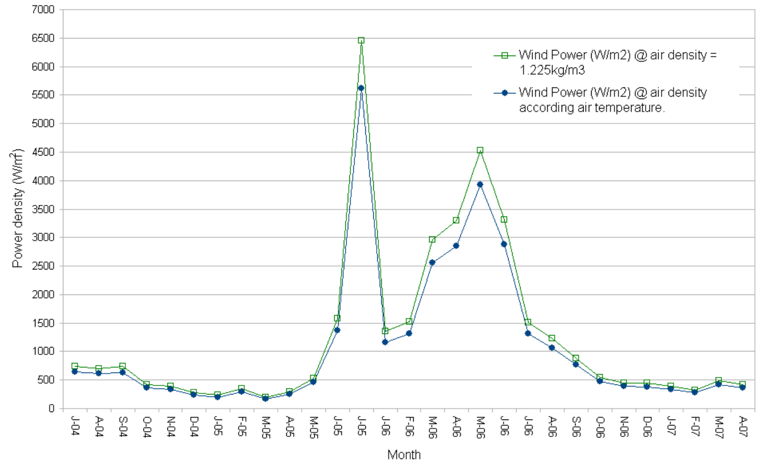

Figure. 5. Monthly wind power average @ 50m with air density changes from Triunfo meteor station

Finally, the wind map of Triunfo region was developed using WAsP program. Figs 6 and 7 shows the wind speed and wind energy density map from the most propitious area in Triunfo zone, with a grid of 70 rows X 70 columns with 500m of resolution, covering an area of 1.220 km^2.

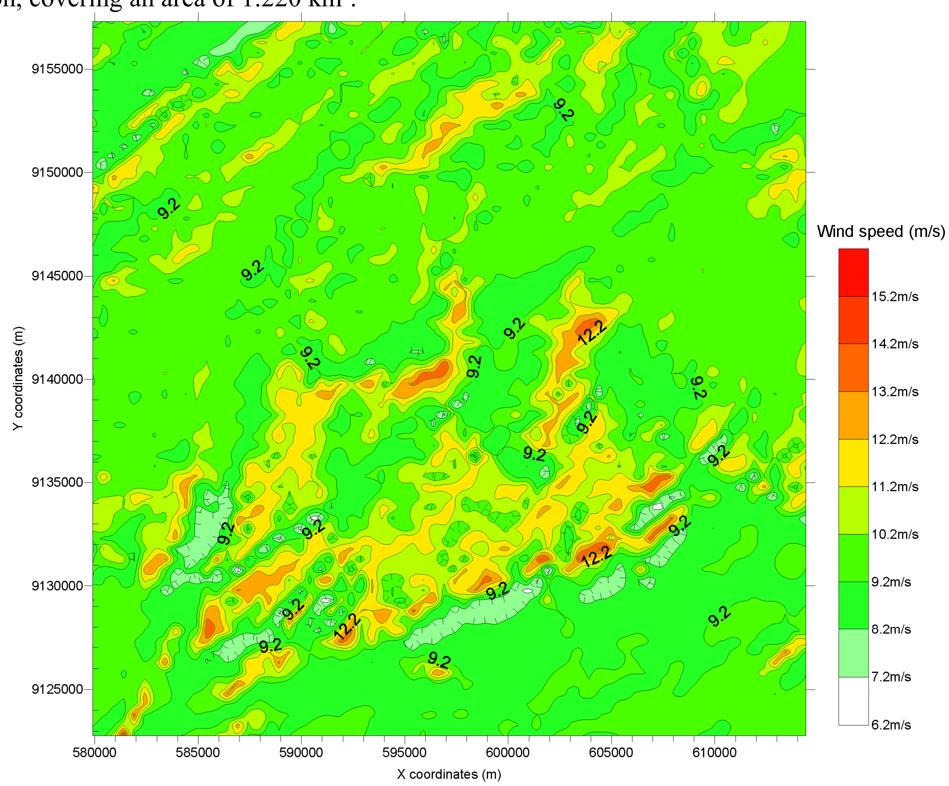

Figure. 6. Triunfo wind speed map @ 50m (70 rows X 70 columns with 500m of resolution) covering 1.220 km^2 in the neighborhood of Triunfo meteor station

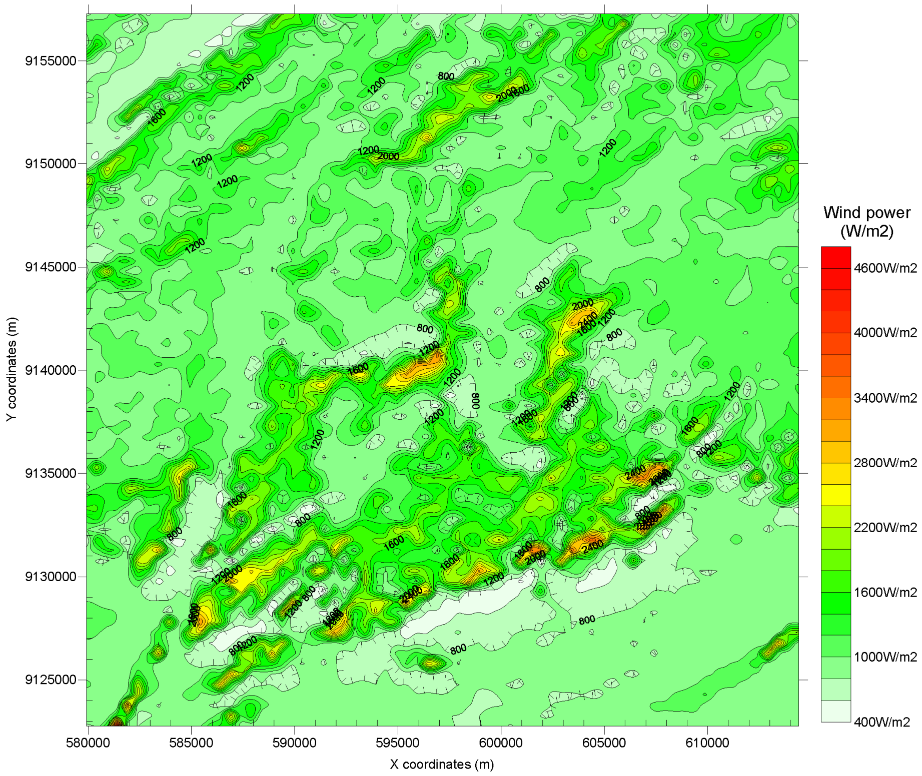

Fig. 7. Triunfo wind power energy map @ 50m (70 rows X 70 columns with 500m of resolution) covering 1.220 km^2 in the neighborhood of Triunfo meteor station.

8. CONCLUSION

As a conclusion of this paper we can remark the follow points:

- Triunfo region has an important and significant wind resources with wind speed mean (V) 11,27 m/s and mean wind power density 1.672W/m^2 . The region must be considerate as a potential area for future wind energy prospections, in especial if we take in consideration the huge positive economical impact for the related region.;

- The wind direction , extremely predominant, to southeast also impact positively for future wind energy prospection. This predominant wind direction influences positively in the overall wind farm efficiency, take in to account that the wind generation would reduce the number of hours used to change its position, when looking for a best wind direction.;

- The air average temperature of 20,20 ºC @ 50m of altitude has a strong impact on the air density value: 1,052kg/m^3 instead of 1,225kg/m^3 (WAsP default value) given and reduction in the final power energy calculate in the order of 6%. This point, refelcs one of the limitation of WAsP and the need to correct the results by using the correct air density, especially for warms regions, like in the Brazilian northeast.

- The Weibull distribution is the more reliable statistic distributions used for wind analyze and makes the wind forecast and characterization more efficient. The values of mean wind speed (V= 11,27m/s) and scale parameter (A=12,7m/s) has a strong correlation (linear correlation factor =0,9988) what confirm correct use of Weibull distribution.

- Weibull shape parameter value (K = 2,0) allowing the use of Rayleigh distribution to characterize the wind speed distribution of Triunfo region;

- The precision and quantity of data's from SONDA project become the final results reliable. This is related to the fact that SOND project use a strong and efficient, quality control of is data's. Additionally the wind parameters, has been take directly at 50m of altitude, which improves the data's robustness ;

- The WAsP program shows robust and reliable tool to make wind characterization and wind energy potential assessment. The WAsP gives to the user, the possibility to work in very friendly environment with the terrain particularities, such as : terrain altitude , relief, terrain surfaces roughness and obstacles, to improve the wind characterization performance.

9. ACKNOWLEDGEMENTS

To Prof PhD Camilo José Carrillo González, who supporting the first author Master thesis and to the Industrial Engineer Department of VIGO University for the use of WAsP

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