

Height Extrapolation of Wind Speed, Experimental and Comparative Analysis

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ABSTRACT: The preliminary wind survey is normally limited by wind speed measurements and registration of information at very great height. This problem is particularly important specially when one intends to characterize preliminarily the relative quality of a determined place for the utilization of wind energy. For this kind of approximation it is neither practical, fast nor economically suitable to install structures supporting sensors at heights between 50 and 100 meters (the most frequently used height ranges for actual aerogenerators) if one doesn't have prior reliable information about general colic conditions of the local region. This work intends to show a procedure which allows preliminary information by means of height extrapolation from experimental wind speed data and average surface density of wind power obtained at two or three different heights and with a proved model of extrapolation. The values are then extrapolated up to a height of 50 and 100 meters. After applying a power law model of extrapolation the results obtained are then compared among themselves as well as with the two experimental wind stations employed. The registration period covers a complete year of data for one experimental wind station (Punta Curaumilla) and eight months for the other one (Llo-Lleo Alto). Data were registered continuously and integrated every 5 and 10 minutes, and were measured at a height of 10 and 15 meters above the ground at Punta Curaumilla and at 10 and 15 meters at Llo-Lleo Alto. This procedure admits the carrying out and the backing up of preliminary studies for wind energy surveys in a shorter period of time with a reduced cost.

Keywords: wind energy, comparison, height extrapolation, wind speed, wind power density

1. ANTECEDENTS, GENERAL DESCRIPTION AND OBJECTIVES.

In spite of the important advances that anyone can observe in many countries, for more than 25 years, concerning technology associated with aerogenerators and wind energy exploitation in the form of electric

energy, Chile presents a great delay on this matter and a national wind survey is still a non solved problem which restricts reliable reference data and therefore limits wind energy projects.

The country has established as a goal in its development policy to accomplish 5% of its primary energy covered by non

conventional and renewable forms of energy for the year 2010, being the lack of that national wind survey a great limitation for the fulfillment of this major objective, specially because wind energy is one of the renewable forms of energy that this country could use in a shorter period of time and all along the country.

This work shows experimental results that can support a methodology to be applied at different potentially attractive sites where future wind energy parks could be located, including a well designed wind survey so as to rely on the good conditions of each place for this kind of projects in a quicker, easier and cheaper way.

Therefore the procedure already applied to data obtained from two wind register stations located a V Region of Chile has been taken as reference. Both stations are sited on the coast border and are separated almost 61(km) one from the other by an imaginary straight line traced between them. These points have relatively similar geographic and weather conditions thus it is possible to contrast the results and to check the important differences that generally exist between two nearby sites. This also rebounds upon the importance of a previous wind survey to back up eolic projects.

Wind speed was measured and registered at two heights at the first anemographic station, Punta Curaumilla, located at the most western cape of V Region coast, with geographical coordinates $33^{\circ} 05' 58,5''$ south latitude and $71^{\circ} 44' 4,9''$ west longitude. The measures were registered every 5 minutes at a height of 15 meters and every 15 minutes at a height of 10 meters. The complete results have already been informed in Ref 8. Data related to only one year (2000) has been employed for this work. A leap year, as it is the year with more complete information gathered at that point (99,85% of annual data that was possible to get with that frequency).

At the second anemographic station (Llo-Lleo Alto), sited on the northern margin and in the mouth of Maipo river with

geographical coordinates $33^{\circ} 37' 41,74''$ south latitude, $71^{\circ} 36' 05,51''$ west longitude, wind speed is being measured and registered at three height stages since August 31st 2006. The instruments are located at 10 and 15 meters and registration of data is generated every 5 and 10 minutes respectively. The results of the first 8 months of measurements considered between August 31st 2006 and April 30th 2007 are informed in this work.

With respect to antecedents above explained photographs of both sites can be seen below



Figure 1: Punta Curaumilla's Cape.



Figure 2: Wind effect on trees.

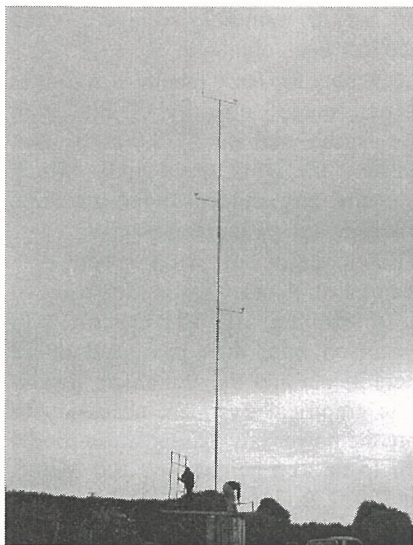


Figure 3: Llo-Lleo Alto's station. Mounting process.

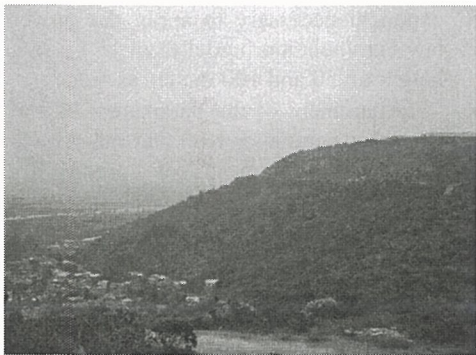


Figure 4: Llo-Lleo Alto's station site

The objectives defined for this work are the following:

- compare the more representative results for a wind survey obtained from data collected at both stations that are: monthly average wind speed and whole period average wind speed, percent of data with speed equal or under 3.0(m/s) (limit speed under which most aerogenerators don't start generating electric power), Weibull wind speed probabilistic distribution parameters, the

statistics probabilistic distribution which offers better fitness to the characteristics of the experimental wind speed distributions and surface density of wind power P/S (W/m^2) that is the main design value for any wind energy project.

- extrapolate wind speed data measured and registered at a height of 15 meters and wind surface density power calculated from those data above ground up to 50 and 100 meters height and compare the results of both stations.
- verify monthly fluctuations throughout the months of the year of these representative results
- percentually compare rates of extrapolated values calculated at a height of 50 and 100 meters with experimental data measured, registered and calculated at lower height, specially in the case of wind surface density power.

2. EXPOSITION OF THE PROBLEM

This work represents a new step of the natural and logic sequence of a systematic plan of measurement and survey of Wind Energy on several interesting places of the V Region in Chile that started a second phase of measurements in 1991.

The general present purpose is to obtain new information from another important place of the coast of the V Region sited on the mouth of Maipo River, necessary data to complement the already known wind energy conditions of other points placed on the central coast of the Region. Uninterrupted measurements of wind speed are being obtained at heights of 10 and 15 meters and wind direction only at the height of 21 meters at this new anemographic station, named Llo-Lleo Alto, measurements and register that begun

on August 31st and will continue at least for one more year.

The specific purpose is to compare these data and results with those already obtained at the other place informed (Punta Curaumilla) where a ten year wind speed data base exists (1995 – 2004) (See Ref. 8). In this work eight months of almost continuous wind speed data from the new Llo-Lleo Alto anemographic station are compared to those similar data and results obtained from the completest year (2000) at Punta Curaumilla. The comparative procedure not only involves wind speed data measured and registered at both anemographic stations, but also those wind speed data extrapolated from 15 up to a height of 50 and 100 meters and monthly wind surface power density calculated at each height at both anemographic stations. It has been considered reasonable for these comparative purposes to obtain and present monthly representative results of wind speed conditions, not only for measured data but also for extrapolated values.

3. METHODOLOGY

In order to secure that values obtained are in correspondence with similar work procedures and focusing an easier later comparison, methodology already employed and applied to the case of Punta Curaumilla has also been used and implemented to the new data from anemographic station at Llo-Lleo Alto. This methodology abbreviated is:

- Classical statistical study, employing all wind speed data measured and registered at 10 and 15 meters height at Punta Curaumilla and at 10 and 15 meters height at Llo-Lleo Alto, data
- $P/S(W/m^2)$ has been calculated, not only for measured data, but also for extrapolated data, at heights of 50 and 100 meters at both stations.
- The precedent results are presented on graphics and tables that allow us to compare the results and differences

from which monthly average wind speed has been obtained

- Calculus for each month of the total and percentage quantity of data with wind speed value $\leq 3,0(m/s)$ that represents the wind speed under which practically any modern wind machine starts generating electric power.
- Extrapolation of wind speed data measured at Punta Curaumilla from 10 up to heights of 15 meters in comparison with data measured at 15 meters height and the attainment hereby of the empirical exponent necessary to apply the power law extrapolation model from 15 up to a height and 100 meters (See Ref. 1, 2, 3, 4)
- Extrapolation of wind speed data measured at Llo-Lleo Alto from 10 up to 15 meters high and comparison with data measured at heights of 15 meters and attainment hereby of the empirical exponent necessary to apply the power law extrapolation model from 15 up to a height of 50 and 100 meters as before.
- Attainment of the parameters K and C (form parameter K(-) and magnitude parameter C(m/s)) of probability Weibull statistics distributions for wind speed data P(V), measured at each station and at each height, employing for this purpose all the monthly data collected. For its accomplishment a two parameters model probabilistic Weibull distribution was applied, as this distribution is the one which offers better fitness to empirical wind distributions.
- Later, wind surface power density

between both stations and for others heights in an easier way.

4.RESULTS

Figure 5: Year 2000, Monthly Average wind speed at Punta Curaumilla station.

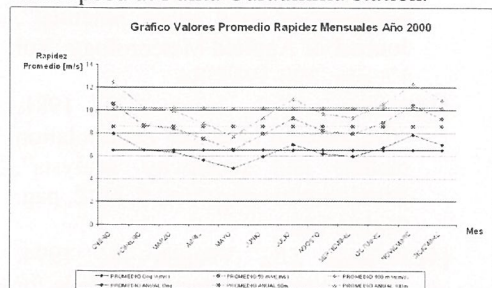


Figure 6: Year 2000, monthly surface wind power density and yearly averages at Punta Curaumilla station (original and extrapolated data).

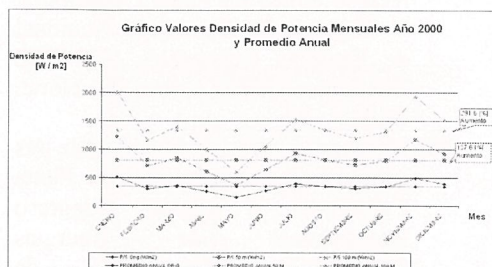


Table I: Monthly relevant data and key parameters for Llo-Lleo Alto station.

MONTH / YEAR	ANEM	HEIGHT	DATA #	N° V<=3.0	Vmax (m/s)	AVG V (m/s)	K(-)	C(m/s)	P/S (W/m²)
Sep-06	A	21(m)	8,749	4.323	10.8	3.08	1.81	3.45	39.65
	%			49.41					
	B	15(m)	4,374	2.947	9.4	2.76	1.90	3.10	27.16
	%			57.09					
	C	10(m)	4,374	3.404	8.8	1.94	1.49	2.15	12.89
Oct-06	A	21(m)	7,518	2.988	12.2	3.59	1.75	4.02	64.67
	%			39.74					
	B	15(m)	3,759	1.801	9.4	3.13	1.72	3.90	42.92
	%			47.91					
	C	10(m)	3,759	2.494	9.5	2.38	1.50	2.64	23.04
Nov-06	A	21(m)	8,640	3.314	12.4	3.67	1.75	4.06	66.67
	%			38.36					
	B	15(m)	4,300	1.945	10.6	3.24	1.74	3.56	44.99
	%			45.05					
	C	10(m)	4,300	2.653	9.6	2.49	1.53	2.76	24.49
Dec-06	A	21(m)	7,910	3.020	14.8	3.83	1.71	4.28	82.09
	%			38.18					
	B	15(m)	3,955	1.733	12.7	3.41	1.76	3.82	55.96
	%			43.02					
	C	10(m)	3,955	2.306	9.9	2.62	1.46	2.89	30.84
	%			58.31					

MONTH / YEAR	ANEM	HEIGHT	DATA #	N° V<=3.0	Vmax (m/s)	AVG V (m/s)	K(-)	C(m/s)	P/S (W/m²)
Jan-07	A	21(m)	8,929	3.482	11.9	3.58	1.75	4.00	63.32
	%			39.00					
	B	15(m)	4,464	1.978	10.4	3.23	1.79	3.61	45.33
	%			44.31					
	C	10(m)	4,464	2.640	9.6	2.52	1.53	2.80	26.50
Feb-07	A	21(m)	8,064	3.675	13.3	3.39	1.64	3.78	59.17
	%			45.57					
	B	15(m)	4,032	2.063	10.4	2.99	1.60	3.33	40.83
	%			51.17					
	C	10(m)	4,032	2.640	8.9	2.32	1.40	2.55	22.43
Mar-07	A	21(m)	8,668	4.143	11.9	3.2	1.66	3.58	49.11
	%			47.80					
	B	15(m)	4,334	2.423	11.3	2.8	1.50	3.10	37.50
	%			55.91					
	C	10(m)	4,334	2.930	10.4	2.28	1.37	2.51	23.52
Apr-07	A	21(m)	8,640	4.406	10.6	3.01	1.66	3.36	40.43
	%			51.92					
	B	15(m)	4,320	2.573	9.9	2.65	1.62	2.95	28.76
	%			59.56					
	C	10(m)	4,320	3.201	9.2	1.99	1.39	2.19	15.48
	%			75.95					

5. CONCLUSIONS AND COMMENTS

If a comparison between original monthly speed averages data measured at a height of 15 meters and monthly surface wind power density calculated from those data is achieved at both anemographic stations, taking as a reference the corresponding minor value for each sample, we got 113,9% and 918,0 % average differences for $V_{avg}(m/s)$ and $P/S(W/m^2)$ respectively.

The same exercise applied to extrapolated data up to 50 meters height from original data and for the same quantities already explained gives 74,9 % and 432,3 % averages differences and gives 52,5 % and 213,2 % averages differences respectively for extrapolated data up to 100 meters of height.

All the results above described give a better performance at Punta Curaumilla station. When original wind speed data under $V \leq 3.0(m/s)$ condition measured and registered at 15 meters at both stations are counted, their percent value over the total monthly and then over the total year data are calculated, obtaining a year average percent of 22,3 % for Punta Curaumilla and of 51,9 % for 8 months at Llo-Lleo Alto. These figures represents the percent of the total year time for each station, where a wind machine eventually installed there at that height, would not generate electric energy.

The best monthly speed average at Punta Curaumilla is January with $V = 7.97$ (m/s) and the lower value is for May with $V = 4.92$ (m/s) (see Figure 5). The similar results at Llo-Lleo station are on December with $V = 3.41$ (m/s) and on April with $V = 2.65$ (m/s) respectively.

The year average surface wind power density $P/S(W/m^2)$ increases from 342,1 up to 812,3(W/m^2) from 15 up to 50 meters of height and from 342,1 up to 1.339,0(W/m^2) from 15 up to 100 meters of height at Punta Curaumilla station. The same comparison at Llo-Lleo Alto for a complete eight months period gives 33,6 up to 152,5(W/m^2) from 15 up to 50 meters and 33,6 up to 427,5(W/m^2) respectively. For the 4 results the reference value is that obtained at lower height.

The results already presented show that much better wind conditions exists at Punta Curaumilla than in Llo-Lleo Alto in spite of the short distance (61 kilometers) between them. It is probably that these better conditions are due to the marine water arising phenomenon existing on the sea at the same latitude of the mentioned station. They also confirm the importance of having a previous and systematic wind survey for every wind project.

The author of this work has the conviction that it is highly recommended to carry out a project for doing a systematic and continuous wind energy measurement and survey up to huge height (50 meters for example) at several sites of the coast of Chile (at least one representative site for each region) in order to count with a reliable information to back up future wind power projects.

REFERENCES

- [1].Justus C.G., Mikhail A.S., 1975. "Height variation of wind speed and wind distributions statistics", Geophysical Research Letters, Vol. 3, N° 5, pág. 261-264.
- [2].Peterson E.W., Hennessey J.P., 1977. "On the use of power laws for estimates of wind power potential", Journal of Applied Meteorology, Vol 17, pág. 390-394.USA
- [3].Mikhail A. S., Justus C.G., 1981. "Comparison of height extrapolation models and sensitivity analysis", Wind Engineering, Vol. 5, N° 2, pág. 91-106.UK
- [4].Rohatgi J.S., Vaughn N., 1994. "Wind characteristics, an análisis for the generation of wind power", Alternative Energy Institute, West Texas A y M University, USA.
- [5].Naveas C., Naveas M., 1996. "Nuevos antecedentes acerca del recurso eólico en Punta Curaumilla, V Región", IX Seminario Nacional de Energías Renovables (SENESE IX), Universidad Católica del Norte, Chile.
- [6].Naveas C., 1998. "Evaluación de tres años de registro continuo en Punta Curaumilla, V Región, Congreso Internacional de Energías Sustentables, Universidad de Magallanes, Chile.
- [7].Naveas C., Naveas P., 2000. "Prospección y catastro eólico comparativo para períodos diurnos y nocturnos en dos puntos de la V Región", 9° Congreso Chileno de Ingeniería Mecánica y IV Congreso Nacional de Energía (COCIM-CONAE 2000), Universidad Técnica Federico Santa María, Chile.
- [8].Naveas C., 2006. "Síntesis y proyecciones de diez años de medición y prospección eólica en Punta Curaumilla, V Región", Congreso Nacional de Energías Renovables no Tradicionales, Departamento de Ingeniería, Universidad de Viña del Mar, Chile.