Physical modeling application to wind power assessment for wind farm installation in complex topography terrain.

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ABSTRACT

Wind power assessment and micro sitting in complex terrain zones using physical modeling technique was developed. For the wind power assessment the physical modeling is used jointly with a numerical model in a nest configuration. The wind velocity field in a coarse grid with a mass conservative model is deduced from data obtained in weather station. This velocity field calculated is the boundary condition for the physical model. Velocity mean and turbulent component are estimated with a difference lower than 5% in the mean velocity and intensity of turbulence. For micro sitting application, the physical modeling results jointly with field measurement are used. The physical modeling results give an idea for optimize the wind generator distribution because a very good flow description is obtained relating to different terrain features.

INTRODUCTION

In the frame of an energy diversification policy carried on Uruguay, renewable energies are considered for electrical energy production. In particular, wind power is considered as alternative. Wind power assessment studies developed since 1988 showed very attractive results. A long coast line, gentle hills next to such place and a particular wind climate gave rise to an exploitable wind resource. Cataldo and Nunes, 1993 presented a wind map of Uruguay developed by Work Group on Renewable Energies (GTER) from School of Engineering. Also, several complex terrain zones were identified where a more detailed wind power assessment was done. As part of the wind power assessment a wind generator with a rate power of 150kW was installed with CONICYT-IBD support. Experience on field wind measurements, selection, installation, operation, test and maintenance was undergone. Also, other renewable energies as solar PV, solar thermal, husk rice and PET combustion were researched. Cataldo and Nunes, 1996 present a summary of such activities. In the wind power assessment special attention was append in the description of the flow in analyzed regions.

Recently, associated to the aforementioned policy, the wind power assessment was encouraged and the design of a wind farm was performed, which will be installed in short time.

Short time field wind measurement underwent in several sites were used to verify models results and for wind power assessment where industrial use could be feasible.

WIND POWER ASSESSMENT IN URUGUAY

Sites or zones wind power assessment implies the wind climate description. Usually, the meteorological information for wind power exploitation isn't know. Then, some methodologies for deduce the wind climate were developed. It must be quoted the following: Wind Atlas (CIEMAT, 2000), numerical models, physical models (Cataldo, 1990), or both in a nested way (López y Cataldo, 1993; Cataldo y López, 1995).

As numerical methodology, it could be quoted the mass conserving models (Sherman, 1978), irrotational flow solutions (CIEMAT, 2000) and turbulent flows simulation.

The flow in complex terrain could be described using physical modeling, but to deduce the velocity history are necessary field data.

Nested methods use two or more techniques for description of the flow at different scales. GTER developed a nested methodology for describe the wind climate in complex terrain regions. A conserving mass numerical model is used to describe the flow at meteorological meso scale and with a physical model the flow is described at meteorological micro scale. Using weather station data as border conditions the numerical model is operated. Applying this methodology is possible describe the mean flow, the turbulent components and analyze the effect of the different terrain features on the flow. Also, it is possible study the wind power in large areas without measurements in a relatively short time.

The wind climate in plain Uruguayan regions was deduced with the numerical model application. The model border condition is in the inner of the studied region. Such border condition was constituted by the data obtained in weather station of the National Weather Directorate of Uruguay. Then, the work begun with quality study of the data and the numerical data was applied on the principal pattern of the ensemble.

The numerical model output was the border condition for the physical model. This second model was used, as it was aforementioned, to describe the flow in complex terrain zones, especially to know the effect of the gentle hills on the wind. The wind power assessment was aimed to exploit the resource at large scale, then, the best places were selected. Such places must present high mean velocity, low turbulence and also a good access way and electrical net proximity. Then, several gentle hills, located in the south were identified as it is showed in figure 1.

Weather station measurement register usually has several discrepancies with the real values. Such discrepancies with different sources can be associated, between others installation misleading, modification of the surrounding, read out mistakes, transmission problems, register errors, etc. Then, an exhaustive quality control based on principal pattern methodology was made. Figure 2 shows a correlated pattern, while in figure 3 an uncorrelated pattern is showed.

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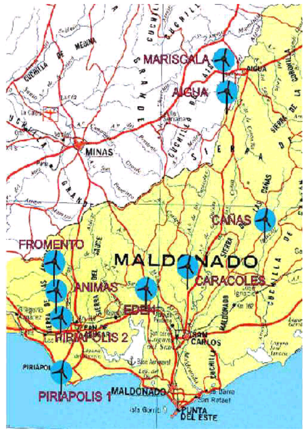


Figure 1 – Analyzed complex terrain zones.

Then, an exhaustive quality control based on principal pattern methodology was made. Figure 2 shows a highly correlated pattern, while in figure 3 an uncorrelated pattern is showed.

Figure 2 – Correlated pattern.

Figure 3 – Uncorrelated pattern

In similar climate region, the principal pattern ensemble gives an idea about the climate pattern. High correlated principal pattern to strongest climate pattern are associated. The low correlated principal pattern to local conditions or misleading conditions could be associated, and the cause of such low correlation could be identified.

Once the different problems are solved, the wind field in the studied zone is deduced applying a mass conserve model to the principal patterns. Figure 4 shows the result of such calculation.

Such practice has the follow advantages: 1 – the climate physical driven are considered, 2 – the errors can be eliminated, 3 – existing data can be used, 4 – a meteorological parameters data base with a better quality is obtained. López, 1997 shows a description of the principal pattern method and its applications.

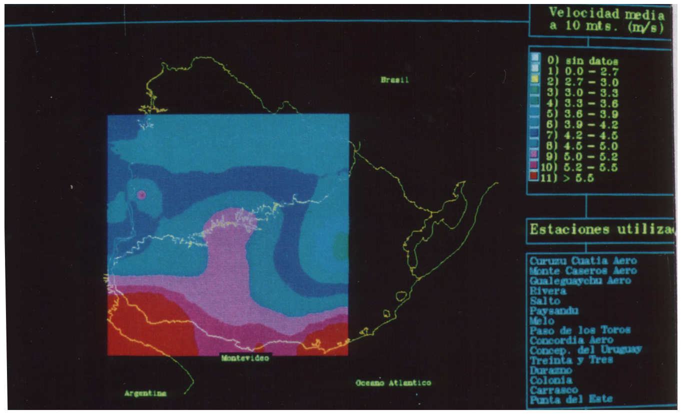


Figure 4 – Annual mean velocity iso-curves

PHYSICAL MODEL DESCRIPTION

Cataldo y Farell, 1992 presented an atmospheric boundary layer (ABL) simulation at 1/6000 geometrical scale for rural terrain exposure. The system described in Counihan, 1969 and Robins, 1979 was used. Elliptical edge vortex generators 10cm high with a castellated barrier 5mm high and a smooth floor were installed. The wood floor was waxed and polished. The velocity measurements were performed using a hot wire anemometer TSI, IFA100 with three channels, film probes, an acquisition system based on a National Instruments A/D board on a PC and a program developed from LabWindows.

A mean velocity profile with a roughness length of 20cm and a power index of 0.17 was obtained. Figure 5 shows such mean velocity profile. Figure 6 shows the longitudinal turbulence intensity profile where a value of 14% at 30m (prototype scale) over local terrain can be observed (H is the boundary layer heght). Figure 7 shows the longitudinal integral scale profile. Such parameter presents a value of 220m at 120m high. Also, the turbulence power spectrum density at different heights was obtained. Figure 8 shows such parameter at 30m high (prototype scale).

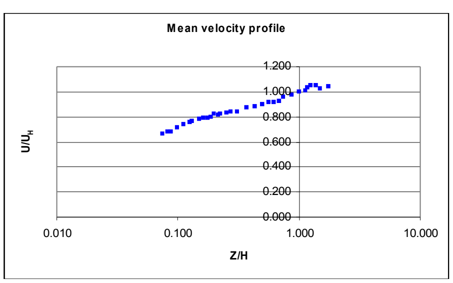


Figure 5 – Mean velocity profile

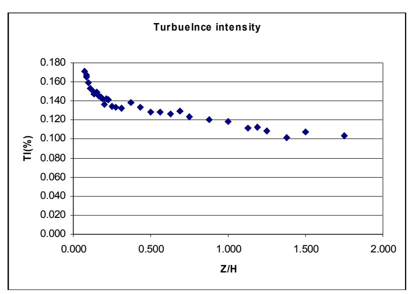
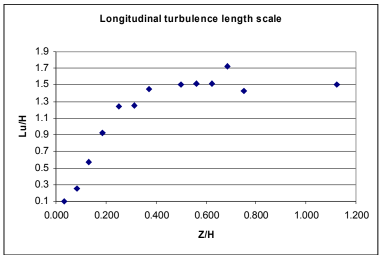


Figure 6 – Longitudinal intensity of turbulence profile

In the described flow ABL like complex terrain zone physical models were operated. In each studied zone, several sites were identified as it showed in figure 9.



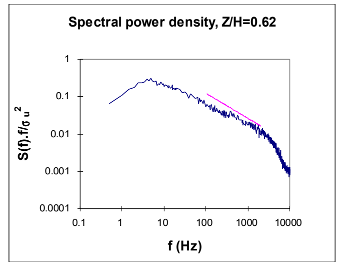


Figure 7 – Turbulence longitudinal scale profile

Figure 8 – Turbulence power spectrum density

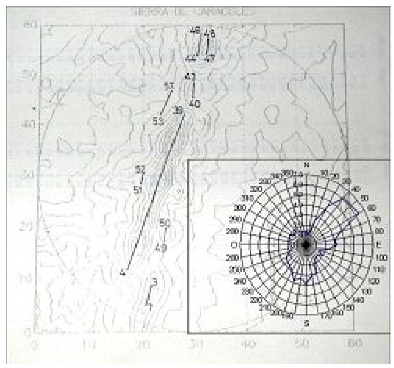


Figure 9 – One studied zone.

Velocity measurement was done at 30m over local terrain at prototype scale, and mean and turbulence intensity in each site was determined. The speed up at such height was deduced over each site. Over some points the mean velocity profile was determined. Figure 10 shows a typical profile in the zone identified as Caracoles zone.

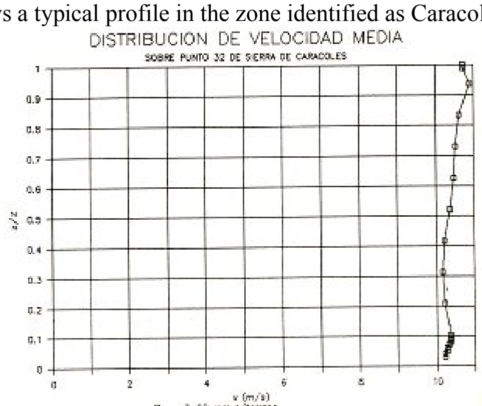


Figure 10 – Mean wind velocity profile over Caracoles gentle hill.

WIND POWER ASSESSMENT

The physical modeling results, jointly with the numerical model results were used to describe the wind climate in each site, where eventually could be installed a wind generator of the farm. A typical physical model result is showed partially in table 1. For each site and for each wind direction the speed up S related to the downstream velocity and the local longitudinal turbulence intensity are estimated. A first site selection with high speed up and low intensity of turbulence can be done. Then, applying the speed up to the wind speed history obtained from the numerical model in the border of the considered zone, a wind speed history could be obtained in such selected site.

Once the speed history in each site is obtained a wind generator distribution could be selected and the energy is estimated. As the wind speed history is knew, the tune of the wind generator to the site can be done. This tuning maximizing the energy production or the capacity factor can be done. Figure 11 shows this tuning schematically.

Site	N		NNE		NE	
	S(%)	I(%)	S(%)	I(%)	S(%)	I(%)
1	1.10	0.18	1.20	0.15	1.35	0.11
2	1.15	0.17	1.25	0.16	1.45	0.12
3	1.20	0.18	1.23	0.17	1.39	0.11
4	1.25	0.15	1.20	0.15	1.41	0.13
5	1.35	0.15	1.25	0.15	1.36	0.12
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n	1.05	0.25	1.40	0.11	1.60	0.12

Table 1 – Physical model result

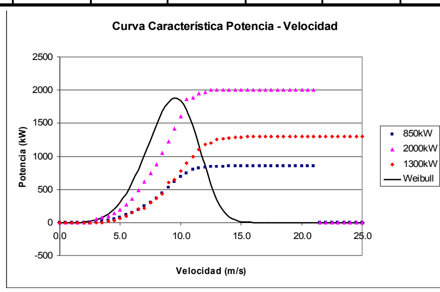

Figure 11 – Tuning sketch

2000kW and 850kW wind generators would have approximately the same capacity factor, while the first one would produce more energy. 1300kW wind generator would have a lower capacity factor but it would produce more energy than the 850kW one.

MICRO SITTING

When a wind farm installation is decided a field measurements campaign minimally one year long is recommended at hub height which is unknown. Micro sitting usual practice is with numerical models. This kind of models usually doesn't take into account the detailed feature terrain and then some difference results can be find when the farm is operated. The physical models take into account all terrain features and then a very fine micro sitting could be made. Then, using jointly the physical model result with the one year field measurement the micro sitting could done. Also, it must be quoted that only one height measurements is needed because of in the physical model wind velocity profile could be obtained. Short field measurement jointly physical model result could be used too. In this case numerical model results are necessary to obtain long velocity histories.

METHODOLOGY VERIFICATION

Along the time the wind velocity was measured on one site of Caracoles zone (see figure 1) at 10m and 48m on the local terrain.

In the lower height a VECTOR Instruments anemometer model R30, with length constant of 5m and a sampling frequency of 1Hz. The data were saved in a computer from which mean velocity value, mean direction and standard deviation of the velocity were deduced. In the higher location a SECONDWIND system was used composed by a vane model A1-NRG 200P and an anemometer model Maximum#40. The constant length is 2m, the sampling frequency 0.5Hz and average values on a period of 10 minutes is accumulated.

Applying the described methodology for wind power assessment, an annual mean velocity of 28km/h and a turbulence intensity typically of between 9% and 15% at 30m height prototype scale were calculated.

From the measurements at 10m an annual mean velocity of 29.5km/h and at 48m an annual mean velocity of 28.4km/h were founded. Figure 12 compare probability density curve of mean velocity and turbulence intensity obtained in both height.

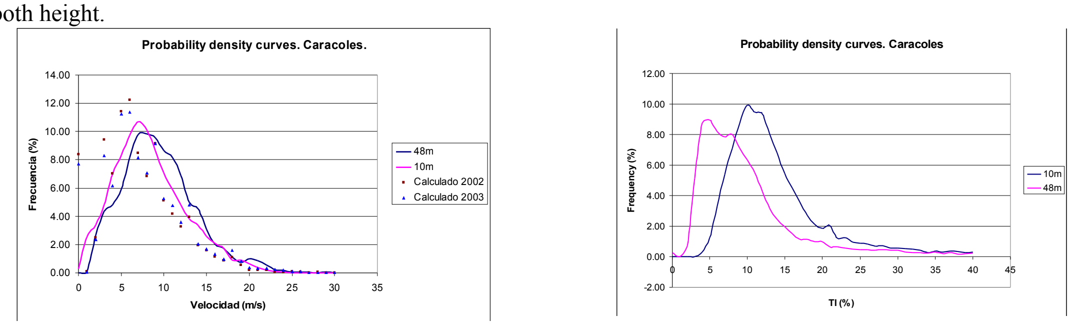

Figure 12 – Probability density curve of mean velocity and turbulence intensity

From the measurements the turbulence intensity at 48m height typically between 5% and 15% and at 10m between 5% and 20% are obtained. Such values are similar to the one obtained from the physical model. It must be quoted that speed up and turbulence intensity change with wind direction. Then, the aforementioned turbulence intensity values to different wind direction are related.

In the mean velocity probability density curves the one obtained from the methodology are included. In this case the peak and the high velocity proportion is shift to lower velocities, but a greater scatter is observed.

CONCLUSIONS

The nested methodology developed by GTER is a precise tool for wind power assessment and for energy production calculation in each site of a wind farm located in complex terrain zones. For the wind power assessment is not necessary take measurements and for guess the energy production is possible describe the wind climate in all site with only one field measurement at one height.

The physical model is a good tool to describe the flow in complex terrain.

The methodology was verified using field data.

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