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Application of IEC 61400-11 in Italian land

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Abstract

Part 11 of IEC 61400 provides the methodology for the analysis of noise emitted by wind turbine generation systems.
In Italy, wind farms are usually located in areas with specific geomorphology and particular wind conditions.
The IEC standard, recently adopted in Italy, was studied in the Nordic countries, where the characteristics of the area are certainly flatter and most relevant in terms of wind energy content.
During the application of the rule on national sites have been identified a number of issues used to put forward some practical suggestions, with particular regard to limits of applicability of the legislation itself.

1.Introduction

From 2000 to 2009 wind farms have been highly developed in Italy, especially in the last few years. At the end of 2006 there were 169 wind farms with a 1908 MW capacity while in 2009 they had increased to 294 (+74%) with an 4898 MW capacity (+157%).
52 new plants were installed in 2009, and the 73% of these have more than 10 MW power.
There are 12 new wind farms included in 1 to 10 MW power class and 2 with less than 1 MW power.
Overall power increased 1360 MW (+38,5%) in 2009 compared to 2008 most because of the more than 10 MW power plants.
Wind farm's average power increased from 6,6 to 16,7 MW in the age from 2000 to 2009.
First in 2010 plant's average growth rate was reduced by 25%, with only 948 MW installed.
Characteristic of territory is a key feature for the setting of wind turbines.
Decisive elements to choose a site are, in facts, wind, topography and site's accessibility.

Fig. 1. Italian Map of Win d Farms (by La Tene Maps and ANEV)

The map in figure 1 was made by La Tene Maps, with the help and assistance of ANEV (the Italian Wind Energy Association) and published in 2010.
The map shows wind farms in Italy with a generating capacity generally over 1MW and include also projects under construction. Wind farms in place are shown as black color whilst those under construction are shown in blue color.
Wind farm's distribution in the country is more concentrated in Southern Italy, where Puglia, Campania and Sicily own 60% of the national installations.
Wind turbine's number in Campania are also increasing. In Northern Italy there are less plants then in Southern and Liguria is the better equipped region. The same is observed in Central Italy.
The distribution of installed power shows a similar situation. Northern Italy's wind farms are few and limited-power compare to national total. Southern regions and islands owns 98% of national total.
Regional distribution of wind power generation shows similar results, with very high values in Southern regions and islands vs. very low or zero values in the northern regions.
As previously pointed out, the difference lies in the lack of installed capacity in many northern regions and, where this capacity is available, to the limited size of the plants. Puglia and Sicilia together account for nearly 50% of wind power generation in Italy and are followed by Campania and Sardinia.
The ratio of installed wind power and surface region shows that in Northern Italy one of the region with the highest value is Liguria. In central Italy is Tuscany. Finally, in the Southern regions there are similar values for Campania and Puglia, with about 59 W/km^2 in 2009. This is due to the fact that Liguria has a small land area. The Southern regions, including Sicily and Sardinia, are characterized by higher values than the national average.
The ratio of installed wind power and population in Northern Italy shows very low values too. This fact is explained by the high density of population of these regions and the small number of wind turbines installed. In Southern Italy Molise has wind power installed value per capita higher because of low population density. Also this indicator shows that all the Southern regions have higher value than the national average.
Wind power production is therefore very high in the Southern regions and islands, while in Northern regions the values are very low or absent.
The characterization of the wind speed of a site is critical and it is crucial to determine the feasibility of the wind farm. The electricity production of wind power is proportional to the cube of wind speed. So small differences in the anemometric conditions of the site can lead to significant differences of the energy really produced.
A generator requires a minimum wind speed (cut-in) of 3-5 m/s and supplies the rated power at a wind speed of 12-14 m/s. This is the main reason why only in certain areas of Italy is possible the construction of wind farms.
The Figure 2 shows the distribution on the Italian territory of annual average wind speed. The data refer to measurements of wind speed at a height of 75 meters (hub height for 1,5 ÷ 2 MW wind turbine generator) above ground level or on sea level for offshore wind farms. We have the highest values of wind speeds on the coasts of the islands and in close proximity of the mountain chains of the Apennines.
In this paper are analyzed the wind farms built in mountain locations, on the Apennines mountains, and they are placed at heights of several hundred meters

above sea level. In fact, the majority of wind farms built on the Italian territory is located in the areas described above.

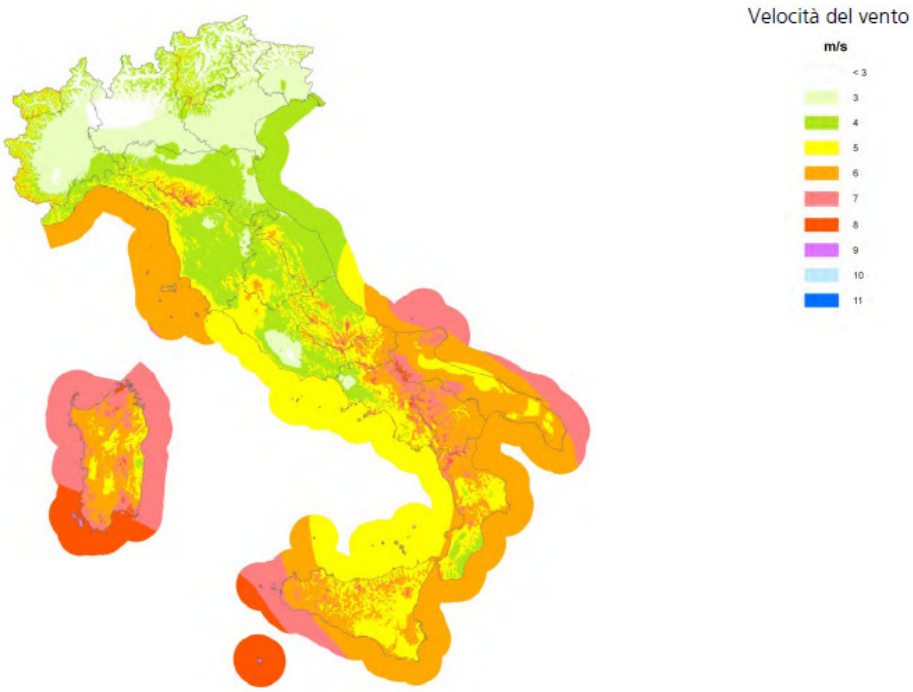

Fig. 2. Map of annual average wind speed at 75 meters on terrain/sea level – (by RSE- Ricerca sul Sistema Energetico)

Fig. 3. Elevation map of Italian land

Both the existing wind farm sites and those in the design phase are usually characterized by strongly directional winds.
Changes in the direction of the wind are often seasonal (i.e. weekly), with annual average speeds never exceeding 5/6 m/s referred to a height of 10 meters above the ground.

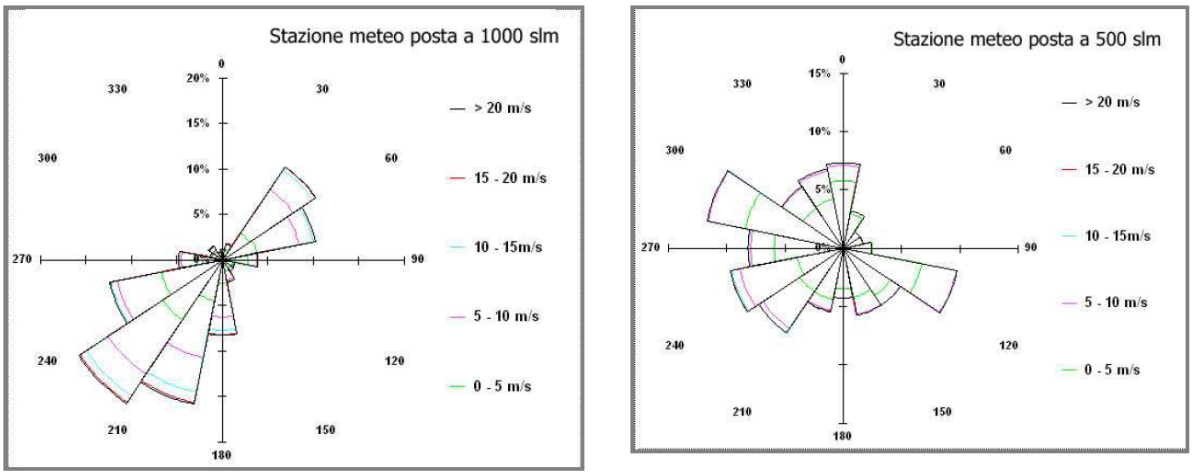

Fig. 5 – Examples of sites wind rose in Marche region

2.The Measurement methods

There are different measurement methods of sound power levels of wind turbine generators. The international method for measuring sound power level of wind turbines is described in the IEC standard 61400 Part 11 “Acoustic Noise Measurement Techniques”.
In Italy the IEC 61400 part 11 was implemented in 2004 as CEI standard (CEI EN 61400-11:2004 “Sistemi di generazione a turbina eolica. Parte 11: Tecniche di misura del rumore acustico”) and was modified with the A1 revision in January 2007.
The IEC 61400-11 provides a uniform methodology that will ensure consistency and accuracy in the measurement and analysis of acoustical emissions by wind turbine generator systems. The revision is about the tonal assessment measurement procedure.
The IEC 61400-11 defines procedures to be used for measurement, analysis and reporting the acoustic emission produced by a wind turbine and specific the non-acoustic measures necessary to define the atmospheric conditions that influence the determination of the noise emissions.
The sound power level of a single wind turbine is determined for reference wind speed of 6, 7, 8, 9 and 10 m/s at 10 m height.
To reduce the effects of terrain, of the weather conditions and of the noise induced by *wind-other body* interaction, the measures must be taken close to the wind turbine, at distance R_0.
The microphone have to be mounted on a flat hard circular board and it is necessary to use one or double windscreen.

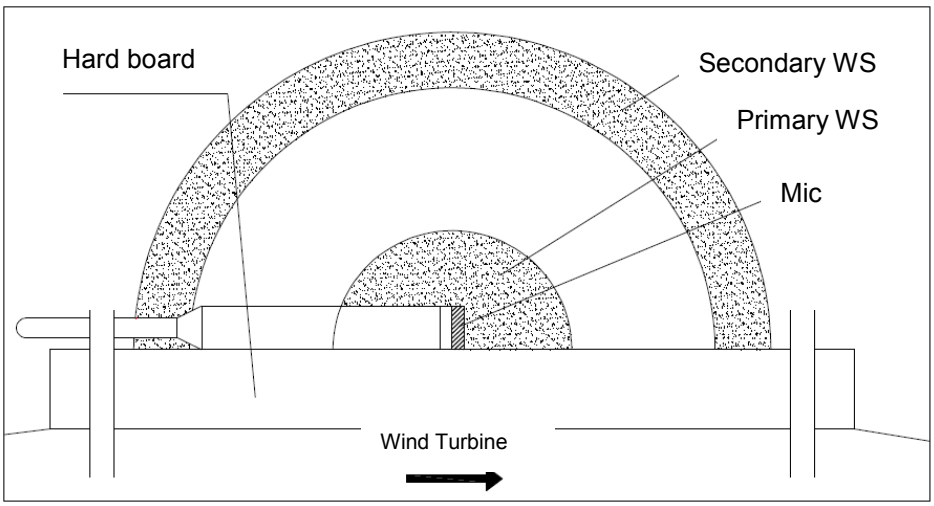

Fig. 6 – Microphone and windscreen (section).

The sound pressure level measurement positions are four (really one and optionally another three) and shall be laid out in a pattern around the vertical centerline of the wind turbine tower as shown in figure 8. The first position is the reference position and it is downwind. The horizontal reference distance R_0 from wind turbine tower vertical centerline to each microphone position shall be with a tolerance of 20%. The reference distance for horizontal axis turbines is R_0= H+D/2, where H is the vertical distance between rotor centre and ground level and D is the rotor diameter. The grazing angle Φ shall be between 25° and 40° with a tolerance of 20% (figure 8). In those conditions the maximum angle Φ is less than 50 degrees (i.e. the 120% of 40° is 48°).
The maximum tolerance for the presence of reflecting structures (walls, dwellings, etc.) close to the measurement positions is 0,2 dB.
The measurements of wind speed and direction shall be done in upwind position, at a height between 10 m and the rotor centre and it have to be in the black area of figure 7.

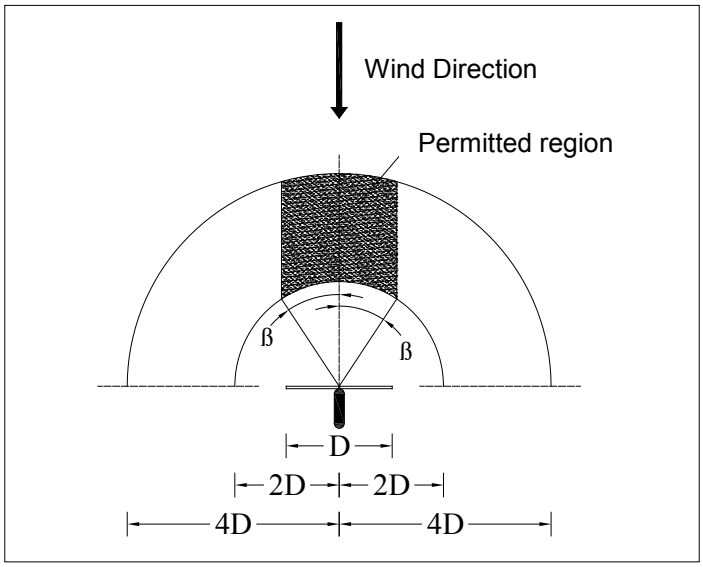

Fig. 7 – Measurement position of wind speed

The angle β is given by:

$$\beta = \frac{z - z_{ref}}{H - z_{ref}} \cdot \left(\beta_{\max} - \beta_{\min}\right) + \beta_{\min}$$

Where z is the anemometer height, z_{ref}= 10 m, the maximum and minimum angle are β_{max} = 90° and β_{min}= 30°.
The acoustic and wind data shall be measured simultaneously, at the integer wind speed of 6, 7, 8, 9, 10 m/s. For each measurement position, are necessary at least 30 measurement (not less than 1 minute) for each integer wind speed. The same number of measurements is necessary for background noise determination. At least three measurements shall be within ±0,5 m/s at each integer wind speed.
The wind speed measured with an anemometer (or calculated) has to be adjusted at level of 10 m and in relation with the reference roughness length z_0 (0,001 ÷0,3 m), with the following equation:

$$V_s = V_z \left[\frac{\ln\left(\frac{z_{ref}}{z_{0ref}}\right) \ln\frac{H}{z_0}}{\ln\left(\frac{H}{z_{0ref}}\right) \ln\left(\frac{z}{z_0}\right)} \right] \qquad [\mathrm{m/s}]$$

Where V_s is the standardized wind speed, V_z is the wind speed measured at anemometer height (z), z_{0ref} is the reference roughness length of 0,05, z_{ref} is the reference height at 10 m, z is the anemometer height.

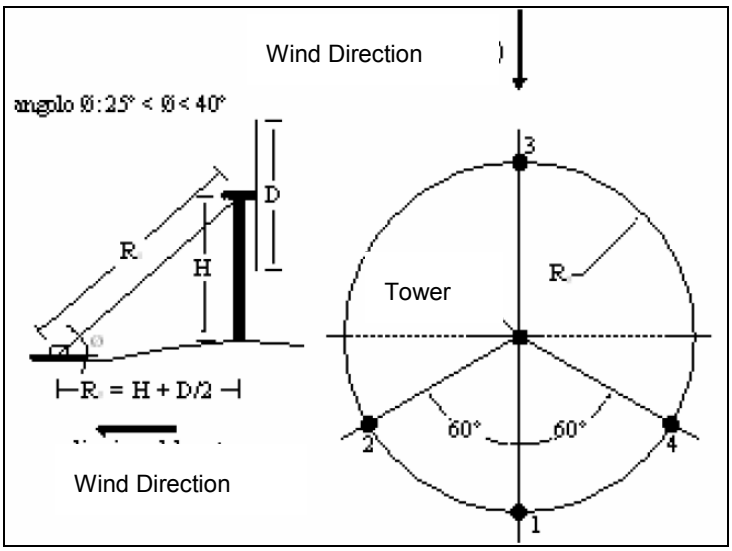

Figura 8 – Test setup.

If the background noise affects the measured noise levels must then be made a correction for background noise.
All sound levels measured in the reference positions, for each integer wind speed from 6 to 10 m/s (bin), must be interpolated using a fourth order regression, to determinate the A-weighted sound pressure level $L_{Aeq,c,k}$, where k is the integer wind speed.

The A-weighted apparent sound power level at integer wind speeds at the reference position is:

$$L_{WA,k} = L_{Aeq,c,k} - 6 + 10\log\left[\frac{4\pi R_1^2}{S_0}\right]$$

3.Case study

To apply the ISO 61400-11 standard was chosen a wind farm located in a site with the typical mountainous topography. The site is in the centre of Italy, in Abruzzo region, and it was repowered in 2007 using new 1,5 MW wind turbines model GE-SLE.

The area on which stands the wind farm is located at an altitude between 1000 m and 1200 m above sea level. From a topographical point of view, the area is very hilly.

The annual average wind speed is of about 5.6 m/s at 10 m above the ground, with the prevailing wind from the W/SW and and E/NE direction.

The wind turbine analyzed is at a level of 1148 meters above sea level. The hub is located at a height of 80 meters above the ground (tower height) while the rotor diameter is 77 meters.

The microphone at the reference position is located downwind at an altitude of 1092 m.

Fig. 9. The case study wind farm

Under test conditions, have been obtained all the sizes mentioned in IEC 61400-11.

The horizontal distance R_0 from the axis of the tower of the wind turbine to the microphone position is:

$$R_0 = 80 + \frac{77}{2} = 118{,}5 \ \ m$$

The gap between the level of the microphone at the reference position and the level of the wind turbine generator is: 1148 m - 1092 m = 56 m. The distance R_1 is: 180,5 m.
The angle Φ between the oblique line R_1 and the horizontal line R_0 is about 49 degrees (48.93°). This exceeds the limits imposed by the CEI EN 61400-11 which provides for Φ a range between 25° and 40°, with a tolerance of 20%.
We proceeded, however, to the calculation of the apparent sound power level.

Fig. 10. Wind turbine generator analyzed.

The IEC standard requires that an interpolation of the data through a non linear regression shall be made. It provides a fourth order regression.
Using a fourth order regression is difficult to obtain acceptable data as a function of integer wind speed values. This is due to the lack of anemometric values over 6 m/s at height of 10 meters. In fact, the Italian average annual wind speeds are usually 5-6 m/s. Using a second order regression is possible to obtain sound power level values only up to wind speeds of 8 m/s.

k **[m/s]**	**$L_{WA,k}$** **[dB]**
6	99,1
7	100,7
8	102,7
9	NC
10	NC

Fig. 11. Apparent sound power levels

4.Problems analysis

The measurement sessions conducted for the characterization of the acoustic power emitted by wind turbines have pointed out several limitations for the applicability of IEC 61400-11.

The data reported above refer to the wind turbine tested, but the comments may be considered generally valid.

The configurations or the presence of mountain slopes that characterize much of the national sites, introduce a series of errors in measurements and in the preparation of measurements setup.

A first observation concerns the position of the table with the microphone measurement, in particular the angle Φ of the plane to the line joining the source-receiver and distances R_0 and R_1.

In the case studied we obtained a Φ value of about 49°, above the limit of the maximum permitted by IEC 61400-11, also taking in to account any tolerances (20°-40° ± 20%).

Other cases present Φ value over 50 degrees, up to a value of nearly 60 degrees.

For example in the case study whether the difference in level between the microphone level and the reference plane of the base of the tower is over 51 meters, the rule does not apply.

When a machine is located near a slope and it is at highest level, the measuring point at a distance R_0 is on a lower level than the level of wind turbine.

The distance between source and measurement point will be greater than R_0, and it increases with the slope of terrain profile.

Higher values of Φ of that allowed remote involves an increase of Source-Receiver distance R_1. The increasing distance Source-Receiver leads to interferences between the sound pressure level of the source and the sound pressure level of background noise. In addition to high distances the environmental impact on frequency analysis is possible.

For example for the case described in this paper the reference measurement point is at an altitude of 56 meters lower than the level of the wind turbine plane.

The measuring point is placed at a distance of 118.5 meters in the horizontal plane from the turbine, so the linear distance between the two is 180 meters. The same distance in the case of receiver flush with the machine would have been reduced to 143 meters.

Even if the measures are made also at the optional measuring points and the ground around the machine has different slopes, the results are not homogeneous. It may happen that the values obtained in the measuring point closest to the machine (R_1 lower) are significantly higher than those at the far measuring point (higher R_1).

Usually in mountain areas, the machines are installed side by side or in line and getting too far away from the studied turbine may mean entering the zone of influence of a nearby wind turbine.

Usually, the distance between two wind turbine generators, by Italian and regional rules, in certain cases must be at least 3 times the wind turbine diameter. A turbine can be at a close distance from another and this can affect different characteristics of the machine which is located downwind.

During measurements on a machine the wind turbines close to that tested will be switched off, but the noise due to turbulence generated by the interaction of the inflow turbulence with the blades and especially with the tower cannot certainly be discarded.

A second important analysis concerns the wind speed in integer values (bins).
As described earlier the Italian territory is characterized by winds that reach throughout the year on an average 5-6 m/s wind speed referred to 10 m high.
Is possible the winds reach speeds over 10 m/s, for short periods, especially in mountain sites, but the very short time of such events and the weather when they occur, make the IEC standard difficult to apply.
The IEC 61400-11 specifics to make measurements in the range of wind speed from 6 to 10 m/s.
The IEC standard requires that an interpolation of the data through a non linear regression. It provides fourth order regression. The regression in the current situation takes place in a limited range of integer values of wind speed, leading to results very unreliable. The use of second-order regressions allowed to obtain the values of apparent sound power in relation to bins of 6-7-8 m/s. To attend realistic values it shall be made a linear regression, but the results are not reliable and they do not reflects the real noise-speed relationship of common wind turbine generators.

Conclusions

In this work the IEC-61400-11 was used in a situation that represents the wind farm installations, which often can be found in the Italian territory.
The case study expressed a number of problems related to the applicability of the criteria imposed by IEC 61400-11 in specific environmental conditions.
As it has been implemented, the IEC 61400-11 standard cannot be fully enforced in the Italian country, but needs to be adapted to real situations that can be found in wind installations. In particular the IEC standard is difficult to apply in mountain environmental contests.

The Italian territory is characterized by winds that reach throughout the year on an average 5-6 m/s wind speed referred to 10 m high. With low wind speeds, the IEC cannot be applied correctly.

The measurement method and the calculation relations have better applicability in countries where wind farms are usually installed in large flat areas, which are characterized by sustained winds (over 8 m/s wind speeds) throughout the year.

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