Towards a national standard to support the assessment of the noise impact of wind farms

Artom F.(1)**, Betti R.**(2)**, Carmagnini A.**(3)**, Lenzuni P.**(4)**, Lodi Rizzini L.**(5)**, Marchisio A.**(5)**, Marsico G.**(2)**, Ziliani R.**(6)

(1) Phoneco S.r.l., Trezzano Sul Naviglio, Milano, Italy
(2) Institute for Environmental Protection and Research, Roma, Italy
(3) Tuscany Regional Agency for Environmental Protection, Firenze, Italy
(4) Italian National Institute for Occupational Prevention and Safety, Firenze, Italy
(5) Renewable Energy Producers Association, Milano, Italy
(6) Cesi S.p.A. - Engineering & Environment Division ISMES, Piacenza, Italy (roberto.ziliani@cesi.it)

Abstract

Specific regulations regarding noise surveys near receptor locations in wind farm sites are currently missing in Italy. Therefore, all tests are performed in accordance with the general national requirements stated by Ministry of Environment Decree 16/03/98. Developers, consultants and regulatory authorities express an increasing need to establish a common approach to deal with noise pollution for this kind of facilities. At UNI - Italian Organization for Standardization, a working group was created in 2008, with the aim to prepare a guideline document to address this specific need and support the assessment procedure. The document, which has the form of a “technical specification”, is currently in its final stage of development. It provides customized measurement and data processing methods, strictly connected to the existing national legislative framework. In the technical specification, salient technical matters are identified and the following issues are addressed: (1) noise measurements near receptor locations in the pre-operational phase for residual noise characterization, (2) noise limits compliance assessment for an existing wind farm and (3) noise impact calculations for planned wind farms.

Introduction

Italy has many laws concerning different features of environmental noise: noise limits for stationary sources, for railway, airport and road noise, acoustic characteristics of buildings, noise pollution measurement techniques and so on. But no document specifically addresses noise from wind farms, which are considered as common industrial sources. The impact assessment procedure is the same as for normal industrial noise sources too. Noise produced by wind farms has very specific characteristics which have to be accounted for with great care not only in the measurement and data processing phase, but also in the noise propagation modelling process. In recent years there has been a growing interest for the use of wind energy in Italy and noise is surely one of the most significant environmental factors to consider. In this context, developers, consultants and regulatory authorities express an increasing need to establish a common approach to deal with noise pollution for this kind of facilities. So, in 2008, a working group (WG in the following) was created by the Italian standardization body (UNI) with the aim to develop a document, in form of a "Technical Specification" (TS in the following), dealing with the topic of wind farm noise. The present document is designed to become the seventh part of UNI 11143 standard [6] (UNI 11143-7). This standard, which deals with noise climate and impact for different kinds of sources, was issued some years ago; it has a general introduction (part 1) and some applicative parts, related to road noise (part 2), railway noise (part 3), noise from industrial settlements (part 5), etc.

The present memory describes the general principles and the main contents of the TS, which is in its final stage of development by the WG and will be subjected to public enquiry in the next months.

Field of application of the TS

The TS defines the methods for describing the acoustic climate and the noise impact generated from wind farms in the surrounding area. This technique can be applied to existing, new or repowered wind farms. It provides practical guidance on the following aspects.

1. Noise immission measurements near receptor locations (residential areas) situated in proximity of existing or planned wind farms. The method is suitable both for ambient noise measurements in the pre-operational phase (residual noise[1]) and for the purpose of assessment after the completion of the plant. Some indications are given also for noise measurement inside buildings[2], required by italian laws [1] [2].
2. Noise impact estimation. An approach is suggested for the preparation of noise impact studies for wind farms, according to the specific features of these sources.

This document does not deal with the calculation of sound power level of wind turbines, which is considered in other standards [4] [5].

The aim of the standard is not to define new approach for the assessment of wind farm noise, based on different indicators and procedures (this is duty of the National Government), but only to define a suitable technical approach for this kind of sources, with the aim of supporting the assessment procedure. Noise limits and indicators are derived from the national legislation. General national requirements about measurement methods are set by the Ministry of Environment Decree 16/03/98 [2] (DMA in the following).

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[1] Residual noise is the ambient noise remaining at a given position in a given situation when one or more specific noise sources are turned off.

[2] Noise immission limits are distinguished in: (a) absolute immission limits, related with ambient noise measured outside buildings, and (b) "differential" immission limit, related to the difference between ambient noise and residual noise, measured inside buildings.

Noise immission measurements near receptor locations

Noise immission level is strictly related to ambient noise level, i.e. the equivalent continuous A-weighted sound pressure level produced by all the sound sources acting in a given place at a given time. It is composed by residual noise and specific contributions of all noise sources.

The TS gives a step-by-step procedure to implement the survey, dealing with the planning phase, the measurement phase and the data processing phase. The general principle that underlies the methods outlined in the TS is that noise measurements must be carried out together with wind speed measurements on the wind farm site and near the noise monitoring station. All the equipment must be synchronized. So, the following parameters must be acquired at the same time, over consecutive measurement periods:

1. time series of overall and spectral noise levels;
2. time series of wind speed and direction characteristic for the plant site, through one of the following procedures:
    a. by means of an anemometer placed on the plant site, a situation which can occur frequently in the pre-operational phase and during early operating period;
    b. through the power curves of wind turbines, considering their electrical power output;
    c. by the anemometers on the wind turbine nacelles;
3. time series of wind speed affecting the microphone, by means of a local anemometer placed in proximity of the noise measurement position;
4. time series of the meteorological parameters (temperature, humidity, pressure, rainfall) recorded by a local weather station.

In case of measurements with the wind farm in operation, it is necessary to gather the power output data for the turbines during the survey, in order to take into account the actual level of operation.

Measurement methods

Two different measurement methods are proposed in the TS:

- long-term unattended monitoring survey;
- short term measurement survey.

With the “long term” method, the measurement lasts several days with no interruptions, while with the “short term” method the total measurement duration consists of only a few hours.

The best method to describe environmental noise on a wind site is long-term monitoring survey with acquisition of wind speed data by automatic measurement instruments. The measurement microphone must be supplied with a mounting kit for outdoor use and equipped with the standard windshield provided by the manufacturer for this type of installation. The sound level meter is normally placed in an airtight casing, and the connection must be made through a microphone extension cable. The total duration of the measurement survey must guarantee that the data obtained are representative of the characteristics of the wind site (with reference to long-term statistics anemometers, generally available for different wind sites). A typical survey could last one week, but some conditions regarding the number of valid samples collected must be fulfilled, as specified below.

The "short term" measurement technique consists of carrying out a series of repeated, usually not consecutive measurements, spanning a total time of several hours. In this case, too, it is compulsory for the noise measurement to be in sync with the wind speed data gathering. The operator supervises the survey and records circumstances and events occurring during the measurement. The microphone is equipped with its standard windshield, it is to be mounted on a tripod and it may be connected to the sound level analyser through a microphone extension cable. The short-term technique can be used near a receptor location in those cases when it is not possible to install a long term monitoring station, as well as in case of noise surveys inside buildings. In this case the TS suggests to perform short term measurements in conjunction with the instalment of a reference station outside the building.

If the monitoring campaign is aimed at determining the noise contribution of the wind farm on environmental noise level, the best measurement method is the one requiring temporary shutdown of the wind farm. Measurements must be conducted with the same procedures in both the wind farm operational conditions, collecting noise level and wind speed values at the wind site, in order to guarantee comparability of data. The TS suggests to plan consecutive series of arrests and restarts of the wind turbines, allowing the acquisition of at least 5 or 6 valid measurements. Alternatively, prolonged out of service phases can be planned and balanced with other phases of operation.

Setting of the noise measurement system

The TS defines the basic dataset of sound level parameters that has to be acquired:

- A-weighted equivalent sound pressure level (L_{Aeq});
- A-weighted percentile levels L_{A10}, L_{A50} and L_{A90};
- 1/3 octave band spectra of equivalent level (L_{eq}) and minimum level (L_{min}).

Optional requirements might be:

- 1/3 octave band spectra of percentile levels L_{10}, L_{50} and L_{90}.

The value of measurement interval (T_P) should be chosen considering the average time of the plant anemometer or of the electrical power output data logger, in order to allow a precise synchronization between noise levels and wind speed data. The value of T_P = 10 minutes is commonly used in wind energy environment; it is the average time used for the determination of the power curve and is therefore indicated as the most suitable choice for this type of investigation. Shorter measurement times can be used too, but in this case the measured data will need to be collected in time blocks of the requested length T_P during the post processing phase.

The TS provides practical hints about measurements. The measurement point should be representative of the receptor's position. Particular care is to be given to the most exposed façade of the building and to any areas outside the living spaces, available for rest and recreation (such as gardens, patios, terraces). When installing the measuring station, the operator must be careful not to place it close to trees, vegetation or structures, whose interaction with wind could locally affect the noise measurement. The distance of the microphone from reflective surfaces must be at least 1 m, but over 5 m would be preferable. The microphone must be installed at 1.5 m above ground level.

Wind speed data

The wind speed range of interest in the application of the TS goes from the $V_{cut\text{-}in}$ to the wind speed corresponding to the maximum sound power level of the wind turbine ($V_{m.n.e.}$ in the following). The wind speed must be referred to the hub height of wind turbines. The TS does not define a specific wind speed profile model to be used for the calculation of wind speed at different heights, but the equations used must be thoroughly discussed in the technical report.

Data processing

At the end of the survey, for each measurement position, time series of overall and spectral noise parameters, wind speed at plant site and at the microphone position, meteorological parameters and, possibly, electric power output, will be available for processing. Data processing and calculation of reference noise levels must be performed through the following phases:

1. <u>Detection of measurement periods affected by adverse weather conditions</u> (excessive wind on the microphone, rain, snow) - The measurement periods during which wind speed on the microphone has been higher than 5 m/s (average value over the measurement time), as indicated by DMA, must not be considered. In case of automatic measurements, the detection of rainy periods is done by analysing the data measured by the weather station placed near the noise monitoring position. For short-term manned surveys, adverse weather conditions are reported by the operator.
2. <u>Definition of homogeneous groups</u> - Each measured sample is assigned to an homogeneous group. Groups are defined according to the most significant variables: reference time (day-time and nighttime required by [1]) and operating conditions of the source. Possibly, if the number of valid data is sufficient, additional variables that may be introduced are: wind direction (receptor up / downwind from the source), weather conditions (stability / instability), working / non working day, and so on. Within homogeneous groups, each record of collected data is therefore assigned to the corresponding class of wind speed at hub height of wind turbines. Each class has an amplitude of 1 m/s and is centered on integer values from $V_{cut\text{-}in}$ to $V_{m.n.e.}$.
3. <u>Detection of unusual events</u> - As established by existing national legislation, ambient noise level is the reference parameter for noise immission level assessment. It has to be purged of all those sound events which can be identified as unusual in relation to the environmental values for the zone and

corrected for tonal and impulsive content in the measured sound [2]. Therefore, the calculation of the equivalent level of each homogeneous group and class requires the deletion of unusual events. The TS states that this operation can be carried out manually or automatically, using percentiles of sound level distribution, with the application of statistical methods.

With manual procedure, the detection of unusual events occurring during measurements is done through a detailed analysis of the time series of measured parameters (L_{eq}, L_N, spectra). Other elements that may be helpful in the analysis are the spectra of percentile levels. This phase may become easier by setting sound level thresholds on the measurement equipment, with the activation of specific instrumental settings or audio recordings when the thresholds are exceeded. The measurement periods that have been identified as unusual are marked and excluded from the calculation. If the measurement time is less than T_P, being T_{ev} the total duration of abnormal events within the measurement period T_P, all periods in which $T_{ev} > T_P/2$ are deleted. J_S indicates the number of discarded periods.

The first step of automatic procedure is the recalculation of L_{Aeq} for each measurement period. This phase is based on the use of percentile levels, acquired directly in each measurement period or obtained during post processing by combining shorter measurement times. The standard deviation σ of the noise levels is calculated for each measurement period j by means of the following relation:

$$\sigma_j = \frac{(L_{50,j} - L_{90,j})}{1,28}$$

assuming that noise levels are normally distributed. The correct equivalent level of each period j is then calculated as:

$$L'_{Aeq,j} = L_{50,j} + 0,115 \times \sigma_j^2$$

Then arithmetic mean L_{Med} and standard deviation σ_{Med} of equivalent levels in each class and group are calculated as follows:

$$L_{Med} = \frac{\sum_{j=1}^{J} L'_{Aeq,j}}{J} \qquad \sigma_{Med} = \sqrt{\frac{\sum_{j=1}^{J} (L'_{Aeq,j} - L_{Med})^2}{(J-1)}}$$

The rejection threshold level L_{max} above which $L'_{Aeq,j}$ must be discarded is calculated by means of the following equation:

$$L_{Max} = L_{Med} + K \times \sigma_{Med}$$

The quantity K is a function of the number of periods belonging to each class and group. Values are, e.g., 0,967 for 5 periods, 1,335 for 10 periods, 1,668 for 20 periods, 2,062 for 20 periods, 2,330 for 100 periods. If $L'_{Aeq,j} > L_{Max}$, the period is excluded from calculations.

4. Check of minimum number of samples in groups and calculation of reference parameters

   The measurement campaign should provide a sufficient number of data among the speed range of interest ($V_{cut\text{-}in} \div V_{m.n.e.}$). The condition set in the TS is to have at least 3 valid measurement periods of duration T_P for each class in each homogeneous group. If this condition is fulfilled, the equivalent level of each class in each group, is calculated as the log-mean of the remaining ($J - J_S$) equivalent levels.

$$L'_{Aeq} = 10 \times \log\left(\frac{\sum_{j=1}^{J-J_S} 10^{0,1 \times L'_{Aeq,j}}}{(J - J_S)}\right)$$

5. Study of the correlation between noise and wind

   Within each homogeneous group, the regression line on L'_{Aeq} data at different wind speed is calculated. This regression can be used to interpolate the data if a wind speed class is missing. The TS gives formulas for the calculation of the regression line.

Checking compliance with community noise limits

The Italian legislation regarding noise pollution is based on the “Framework law on noise pollution” n° 447/95 [3]. The fundamental tool for noise regulation is the noise classification plan (i.e. zoning), that must be set by each City Council. In the zoning plan, the territory is divided into acoustically homogeneous areas on the basis of the main effective or intended use of the same area. There are six kinds of classes, starting from “Protected areas” (class 1) to “Exclusively industrial areas” (class 6). Emission and immission limits are established with reference to the aforesaid classes for daytime (h. 6.00 ÷ 22.00) and nighttime (h 22.00 ÷6.00) reference times. The noise levels are evaluated as A-weighted equivalent sound pressure levels (L_{Aeq}) during these periods.

The TS provides guidance on the criteria for assessing compliance of a wind farm in operation with community noise limits, according to the results of measurements carried out as previously described. All the reference levels must be related to wind speed at hub height of wind turbines.

The tabulated data of L'_{Aeq} at various wind speeds and for each homogeneous group in daytime and night time, represent the rating levels to be compared with absolute immission limits, according to the municipal acoustic zoning.

The assessment of the differential immission level requires the shut down of the wind farm and the measurement of noise levels inside buildings. The short-term measurement method can be successfully used. Differential immission levels are given by the arithmetic difference between ambient and residual noise levels. Threshold applicability levels stated by [1] must be considered.

The emission level of the wind farm can be calculated as the log-difference between ambient noise level and residual noise level, whenever the difference between the two levels is equal to or greater than 3 dB.

Presentation of results

A paragraph of the TS deals with the contents of the survey report, which should be organized in two distinct parts: (a) survey's results and (b) data processing and calculation of reference noise levels. Beside the general indications about measurement reports described by DMA and UNI 11143 [6] standard, in the TS more elements are introduced: the description of the wind data source, wind conditions during the survey, results of surveys in form scatter plots (noise vs. wind at hub height) and time histories of noise and wind parameters. The description of the data processing and calculation phase must include at least the following information: criteria for selection of data, homogeneous groups and excluded periods. The final results must at least present the values of L'_{Aeq} of each homogeneous group for wind speeds from $v_{cut\text{-}in}$ to $v_{m.n.e.}$, together with the calculated uncertainty of L'_{Aeq}, the mean values of L_{A90}, the number of records acquired and the calculated regression lines. The report for an operating wind farm must also include the description of the installed turbines and the wind farm operating conditions during the measurement campaign.

Noise impact estimation of wind farms

The noise impact estimation for a new wind farm or for the repowering of an existing one must be conducted in two phases:

1. acoustic characterization of residual noise, according to the procedures previously described;
2. estimation of noise immission levels after the completion of the wind farm. (This phase requires the calculation of the noise level produced by the plant by means of a noise propagation model).

The main steps for the completion of phase 2 are described in the TS:

- sound power data recovering;
- mathematical modeling;
- analysis of simulation results, in relation to community noise limits;
- basic content of the noise impact report.

Sound power data recovering

The following basic information about sound power data, in accordance with IEC 61400-11 [4], must be available for planned wind turbines:

- apparent sound power level L_{WA} at different wind speeds;
- sound power spectrum of the wind turbine, expressed in octave or 1/3 octave frequency bands;

- directivity.

Other data to be acquired from the manufacturer are: v_{cut-in}, $v_{cut-out}$ and $v_{m.n.e.}$, regulation and hub height of the turbine. The wind profile equation used to transfer wind speed at hub height must be indicated in the report.

Mathematical modeling

The TS provides a list of documentation to be acquired: orography of the plant site and of the surrounding area for an extension of at least 1.5 km around the wind turbines, location, size and acoustic characterization of wind turbines, location and characteristic of all the receptors, characteristics of natural or artificial shielding, sound absorption characteristics of the ground, land cover, long-term wind speed and direction statistics of the site and weather conditions (air temperature, relative humidity and atmospheric pressure).

The TS defines the minimal features of the noise propagation models to be used. It must be able to manage at least the following items:

- sound power spectral data;
- orography of the site;
- attenuation terms due to geometrical divergence, atmospheric absorption, reflecting characteristics of the ground, attenuation due to screening, effect of reflection from vertical surfaces.

A basic request for the model would to be able to represent the “worst case” situation of “downwind propagation” (i.e. the wind is blowing from the turbine to the receivers).

In the annex B of UNI 11143-1 a list of noise propagation algorithms is given. The TS allows the application of both simplified propagation formulas, based on general conservative assumptions, and of more complex propagation models. In both cases, the calculation hypotheses and the input factors must be clearly described in the noise impact report. The assumptions must be conservative enough to ensure the compliance of the operational wind farm.

For the purpose of calculating noise propagation at a distance in the area surrounding the wind farm, each turbine can be represented by omnidirectional point sources placed at hub height, at the rotor center. More detailed representations, e.g. involving the directivity or a more complex pattern of noise sources, can be used, but they must be described in the noise assessment report.

In the TS some hints for the application of the widely used ISO 9613-2 [7] standard are suggested. For ground absorption coefficient (G) a value not exceeding 0.5 is recommended.

Noise simulation must be performed at different wind speeds at hub height, including at least V_{cut-in}, $V_{m.n.e.}$ and the annual average wind speed of the site. The noise prediction can be performed by assigning the same wind speed to all turbines. Calculations may be performed in terms of sound pressure level at receiver locations or contour maps. In the first case the calculation must be referred to different wind speeds, as stated previously. On the other hand, noise contours may be produced only with reference to $V_{m.n.e.}$. The calculation height must be set at 1.5 m above ground level.

Analysis of simulation results

The TS deals with the comparison between predicted noise levels and community noise limits. The noise emission level of the wind farm is represented by predicted noise levels near receptor points. These values, calculated with reference to $V_{m.n.e.}$, are to be compared with the limits set by the acoustic class of the receiver. The immission level at receptor locations is calculated by the log-sum of the measured residual noise level and the calculated contribution the wind farm, at different wind speeds, for daytime and night-time period. Within an impact assessment, the differential immission level can only be estimated outside buildings, using arithmetic difference between immission level and residual noise level.

Contents of the of noise impact assessment report

The content of the noise impact assessment report is described in national general legislation or in regional legislation about environmental noise, issued in implementation of [3]. In addition to these requirements, the TS indicates some information that has to be presented in the report, relating specifically to wind farms: long term wind statistics, features of the planned wind turbines considered within the study, apparent sound power levels at various wind speeds, wind profile equation adopted in the study, predicted noise contribution for the wind farm on the receptors at different wind speeds, with reference to the defined homogeneous groups, absolute immission levels, estimated differential level.

Simplified method for the assessment of wind farms

The TS accepts a simplified procedure for the assessment of wind farm noise impact in the following cases:

- within the area of influence of the wind farm there are no receptors;
- mathematical modeling under conservative assumptions provides, at the most critical receptors, noise levels lower than 30 dB;
- the overall sound power level of the wind farm is reduced (i.e. for the replacement of obsolete equipment with quieter ones or for the removal of some turbines).

Within this simplified approach, the TS does not require experimental campaigns, but only noise prediction calculations, with reference to $V_{m.n.e.}$. Noise contours in the area surrounding the plant must be produced. Whenever the total sound power level of the wind farm has been lowered, the reduced impact, compared to the previous situation, must be demonstrated.

TS attachments

The TS has some informative attachments, dealing with (a) the basic instrumentation requirements, (b) a glossary for wind turbines and (c) methods for reduction of wind induced noise on microphones.

Conclusions

The wind farm noise TS deals with noise immission measurement near receptor locations and noise impact calculation. The TS introduces some measurement methods and noise impact calculation suitable for wind farm noise, with the aim of supporting the assessment procedure, with reference to the existing legislative framework. The document is in its final stage of development and will be subject to public enquiry in the next months; some topics are still under discussion by the WG, e.g. the detailed procedure for the assessment of noise levels in relation to acoustical zoning, the detection of tonal components and some topics about noise impact estimation.

This document acts as a starting point: after some years of application, it will be reviewed to improve the measurement methods herein described and to introduce a more specific and complete assessment approach, based on different indicators and procedures, according to scientific and technical developments in this field.

References

1. Italian Prime Minister Decree 14/11/1997 “Noise immission, emission, warning and quality limits determination”;
2. Italian Ministry of Environment Decree 16/03/1998 “Noise pollution description and measurement techniques”;
3. Italian Parliamentary Law no. 447/1995 “Framework Law on Noise Pollution”;
4. International Standard IEC 61400-11 “Wind turbine generator systems - Part 11: Acoustic noise measurement techniques”;
5. International Standard IEC 61400-11-Am1 ed. 2.0 2006-05 “Amendment 1 - Wind turbine generator systems - Part 11: Acoustic noise measurement techniques”.
6. National standard UNI 11143:2005 “Acoustics - Method to evaluate the acoustic impact and environment for different kinds of sources”
7. International Standard ISO 9613-2:1996 “Acoustics -- Attenuation of sound during propagation outdoors -- Part 2: General method of calculation”.