Issues on the evaluation of low frequency noise emitted by wind turbines

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ABSTRACT

The new European Directive "Road map for low carbon economy to 2050" shows the way to improve the energy efficiency and the renewable sources play a fundamental role to fulfill this goal. Despite wind energy is one of the most efficiency renewable energy, the wind farms' design require an accurate environmental impact assessment, due to noise emission and of visual intrusion on landscape. In particular, low frequencies components of wind turbine noise are recently indicated as one of the possible main causes of noise annoyance. In this work issues about annoyance evaluation are pointed out, taking into account legal requirements, administrative procedures and technical approach for noise control.

Keywords: Power generation and transmission I-INCE Classification of Subjects Number(s): 14.5.4

1. INTRODUCTION

The development of the exploitation of the wind as renewable energy source is surely desirable in the immediate future and to boost at long run . A wind farm does not produce any polluting emissions but even so it has an impact on the environment that has to be assessed since the design stage : specifically a careful evaluation of the acoustic impact of the wind farm is needed.

However this conventional border is arbitrary because a infrasound frequency could become audible according to the level of the intensity, therefore no physical difference between sound and infrasound can be found in the audible range except for the value of their frequency.

As a matter of fact infra sounds grow into perceivable when their pressure level is high. Speaking about low frequency noise (LFN) refers in some cases to a frequency range between 10 Hz and 200 Hz, in other cases to a range between 10 Hz and 160 Hz (Danish legislation). Low frequency noise, usually known as infrasound if below a limit frequency, can become particularly bothersome and has to be regarded with special attention [3,4].

2. SOUNDS AND INFRASOUNDS FREQUENCYS

2.1 Considerations on noise emissions from wind turbines at audible frequencies and Low Frequency noise

Wind turbines can emit low frequency noises mainly for the following reasons:

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-Sound disturbance generated by the rotation of the blades;
-Broad-spectrum noise due to aerodynamic phenomena on the blades and on the nacelle;
-Broad-spectrum noise due to the operation of moving mechanical parts.

2.1.1 Sound disturbance generated by the rotation of turbine blades.

One of the ways noise disturbance is produced by wind turbines is the sound generated from the pressure change in the vicinity of the blades that is when the wind impacting on the blades transfers on them part of its kinetic energy giving rise to their rotation. The wind turbines are characterized by different rotation speeds (rpm: revolutions per minute) as a function of their size .It can go from 60 rpm (6.28 rad/s angular speed ω) for micro wind turbines of a few kW to 10 rpm (ω=1.05 rad/s) for large size turbines, bearing in mind that the speed at the top of the blade (ωD/2) can not exceed certain limits just for the induced noise.

Table 0 – Frequency and rotational speed (The range of operating speed of interest as large WECS is highlighted)

rpm	rps	Blade number	Hz	rpm	rps	Blade number	Hz
2	0,03	3	0,10	32	0,53	3	1,60
4	0,07	3	0,20	34	0,57	3	1,70
6	0,10	3	0,30	36	0,60	3	1,80
8	0,13	3	0,40	38	0,63	3	1,90
10	0,17	3	0,50	40	0,67	3	2,00
12	0,20	3	0,60	42	0,70	3	2,10
14	0,23	3	0,70	44	0,73	3	2,20
16	0,27	3	0,80	46	0,77	3	2,30
18	0,30	3	0,90	48	0,80	3	2,40
20	0,33	3	1,00	50	0,83	3	2,50
22	0,37	3	1,10	52	0,87	3	2,60
24	0,40	3	1,20	54	0,90	3	2,70
26	0,43	4	1,73	56	0,93	4	3,73
28	0,47	5	2,33	58	0,97	5	4,83
30	0,50	6	3,00	60	1,00	6	6,00

2.1.2 BROAD-SPECTRUM NOISE DUE TO AERODYNAMIC PHENOMENA OF THE BLADES AND ON THE NACELLE

Noise at low frequencies, can also be generated by the blade profile and by the nacelle. The wind turbines oft he last generation of turbines, such as those considered in the present study, are designed and realized so that this noise is not produced. However as a specific law that prescribes a limit to low frequency emissions, or indicates special measuring methods for the same emissions; currently they are provided by the manufacturers only for some commercial WECS.

2.1.3 LOW-FREQUENCY NOISED DUE TO THE OPERATION OF MOVING MECHANICAL PARTS

Even the mechanical appliances of a WECS can generate, as most of the machines with moving parts, noise emissions at low frequencies. Even in this case, since there is not a specific law that requires their evaluation by measurements or imposes the respect of limits, not all manufacturers provide experimental data on the emitted noise by the mechanical parts of wind turbines at these frequencies.

3. THE SENSITIVITY OF PEOPLE FOR THE LFN

The sound waves of with a frequency lower than 20 Hz are commonly indicated with the term infrasound. On the contrary to what happens for ultrasound, not necessarily infrasound are not audible, because the heaing system is perfectly capable of perceiving ow frequency waves if their level is suitably high. The threshold of hearing as a matter of fact is approximately 77 dB at 20 Hz, rises to 92 dB at 12.5 Hz and reaches 102 dB at 6.3 Hz. Figure 1 summarize, respectively in text and graphics, the most recent determinations of the hearing thresholds at frequencies lower than 100 Hz.

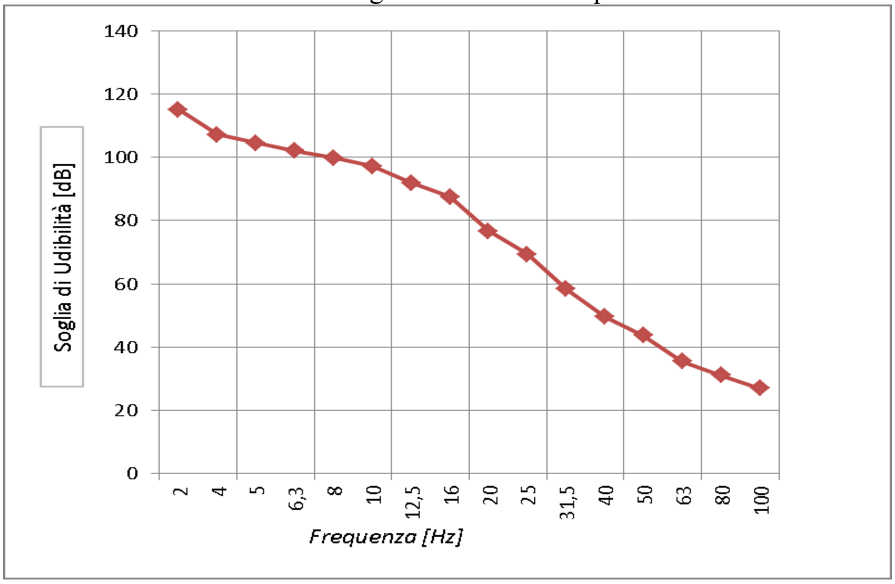

Figure 1 (source: Annex 9 of Guide to exposure to infrasounds, ISPESL 2005) Equations

In Figure 2 the "normalized curves of equal loudness levels are shown, they are taken from ISO 226[8] but can be found elsewhere. Other references on the sensitivity of people to noise at low frequencies produced of the wind turbines are shown in [12,13]

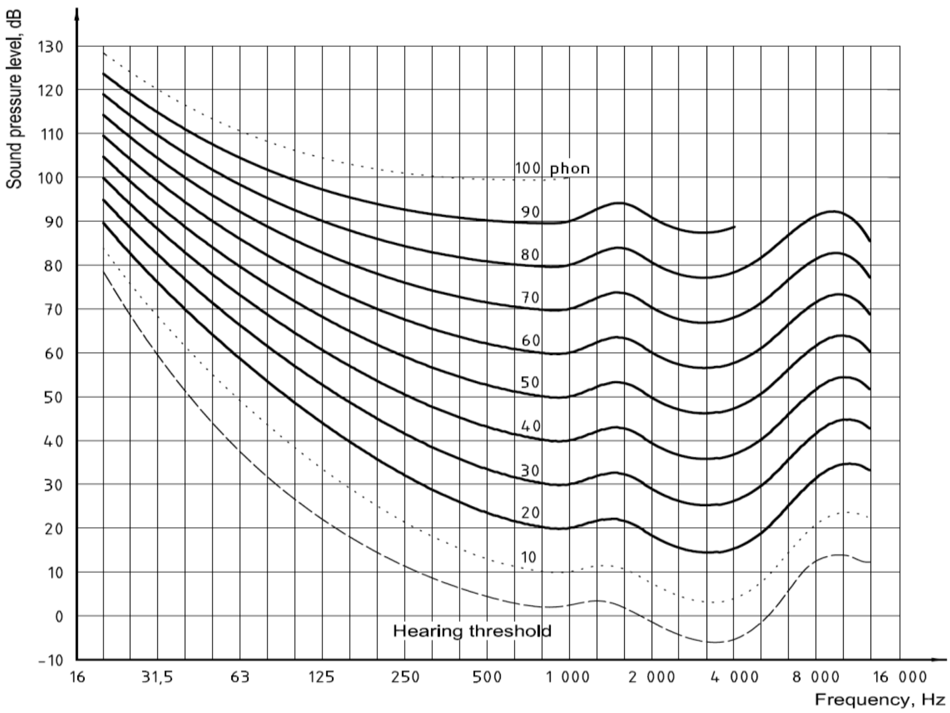

Figure 2 (source: Annex A - UNI ISO 226-2007)

The aim of the present work is to provide elements that are helpful to assess the implications of the presence of perceptible infrasound on the receptors in the same area. Infrasound heve the important feature of becoming very annoying as soon as their sound level exceeds by a few dB the threshold of hearing. The threshold of hearing latter therefore takes on the meaning of threshold of disturbance as well. Therefore, in view of the simple impact prediction, it becomes important to make sure that overruns do not occur, if not occasional, about the sound levels corresponding to the threshold of hearing

4. REFERENCE STANDARDS AND LEGISLATIVE FRAMEWORK

The Italian legislation on noise pollution, until 1995, was based on D.P.C.M. 1.3.1991, staring for the first time the maximum levels of noise exposure in the living environment. With the enactment of the Law 447/95 the fundamental principles are defined for the safeguard of external living environment from noise pollution, referring to several decrees for the completion of the regulatory framework. As regards infrasounds there is currently no reference law that enacts limits for this physical phenomenon. In fact, most of the present rules in acoustics treat and dictate procedures for the field of hearing spectrum normally defined (20Hz-20kHz). Other standards reduces the range of evaluation frequencies to third octave bands for which central frequencies range from 100Hz to 3150Hz.

4.1 Legislative framework for italy and in Sardinia island

The Italian legislation on noise pollution, until 1995, was based on D.P.C.M. 1.3.1991 (Prime Ministerial Decree, March 1st 1991) laying down for the first time the maximum levels of noise exposure in the living environment. With the enactment of the Framework Law 447/95 the fundamental principles for the protection of the external and living environment from noise, referring to several implementing decrees for the completion of the regulatory framework. As regards infrasounds there is currently a reference law that sets limits for such a physical phenomenon. As a matter of fact, most of the rules in acoustics lay down procedures for acoustic assessments in the range of hearing normally defined (20Hz-20kHz), several other standards reduces the range of evaluation frequencies to third octave bands for which the extreme central frequencies are 100Hz and 3150Hz respectively.

The decree of the Ministry of the Environment, D.M. March 16th , 1998 deals with the techniques for detecting and measuring noise pollution by defining the various environmental noise indicators and applying the minimum requirements with which the measuring instruments must comply to ensure that measurements are valid.

In paragraph 11 of Annex B to the DM 16/03/98 is described:

"*Presence of spectral components in the low frequency range:*

If the frequency analysis, carried out in the manner referred to in the previous point, detects the presence of Tonal Components Tonal such as to enable the application of the correction factor K_T in the range of frequencies between 20 Hz and 200 Hz, also the correction K_B as defined in paragraph 15 of Annex A, is applied but only in the night reference time "

From what reported in this annex of the DM above, it appears that the same deree takes into account the low frequencies in the range between 20Hz and 200Hz , exclusively for any present tonal component. The DM says anything except what is reported above, on how to estimating the noise in the whole frequency range of 20-200Hz.

In addition to this we must consider that the survey and estimation methods of the various indicators included in D.M. They must comply with twhat is covered in the section 7 of the said Annex B. The following is the full text.

"The measurements have to be performed in the absence of rainfall, fog and / or snow; the wind speed has to be not greater than 5 m / s. The microphone must be equipped with windshield. The chain of measures must be compatible with the weather conditions of the period when measurements are carried out and in any case in accordance with CEI 29-10(Italian norm) and EN 60804/1994. "

From the above, it can be observed that such survey methods are not applicable whenever the wind speed is greater than 5 m / s. This contrasts with the normal operation of a wind turbine which operates in nominal conditions with wind rated speed of 12-15 m/s. The cut-in speed , i.e. the minimum speed of the wind toallow the wind turbine to start its opation an generation of power varies according to the type, but normally, for the large size turbines as those in question, ranges on average from 4 to 6 m / s. It dependis on the wind turbine type but also on the site where it is to be installed.

In Sardinia, the DGR 62/9 of year 2008 imposed for the calculation of evaluation acoustic impact the use Standard ISO 9613[9,10]. This standard provides for the use of the following relation and the consideration of the following attenuation parameters. This standard It is not normally used to evaluate the noise at low frequencies between 10Hz and 160Hz.

$$L_{eq} = L_w + \mathrm{Dc} - \left(A_{div} - A_{atm} - A_{ground} - A_{screen} - A_{misc}\right) \quad (1)$$

The model allows to calculate the attenuation of noise caused by:

- Distance
- Absorption with atmospheric air
- Influence of soil type
- Influence of any shielding

This equation is implemented in commercial softwares, that allow to upload the mapping of the site (topography, roads, buildings..) and to define the location of the sound sources. In a first phase the equivalent levels of sound pressure as measured (Leq) are entered as input to the software, then the calculation that allows estimation of the acoustic power of the source (Lw) is carried out. Once the sound power levels emitted by the sources are known, we can proceed with the direct calculation, which allows to evaluate the noise levels in all points of the cartography, obtaining maps of noise as those shown in the following figures

4.2 Legislation enacted in other countries

A few years ago, Denmark enacted a law entitled "Statutory Order on Noise from Wind Turbines" , precisely on December 15, 2011. The standard deals with installation, modification and operation of wind farms. Point 8 of section 2 of the legislation, that is included in full; says:

"Low-frequency noise: Noise in the frequency range from 10 to 160 Hz. Low-frequency noise is characterised by the A-weighted level of noise in one-third octave bands from 10 up to and including 160 Hz, calculated indoors using the method set out in Annex 1".

It deals with, as you can notice, the assessment of low frequency noise, more precisely sets a range of frequencies of interest between 10Hz and 160Hz. Finally, it refers to Annex 1 where, in Part I point 1.4, a method of calculation, which is summarized below, is shown.

Assessment of the low frequency noise from wind turbines following the Danish norm

$$L_{p,ALF} = L_{WA,ref} - 10 \cdot \log(l^2 + h^2) - 11 + \Delta L_{gLF} - \Delta L_{\sigma} - \Delta L_a \quad (2)$$

where:

l is the distance from the wind turbine base to the calculation point;

11dB is a correction due to distance, i.e 10 log 4π;

ΔL_{gLF} is the correction for the sound attenuation due to ground effects in the low frequency range (see table 3);

ΔL_{σ} is the correction due to sound insulation in the low frequency range (see table 3);

ΔL_a is the correction due to air absorption ($\alpha_a\sqrt{l^2 + h^2}$) where the coefficient α_a is shown in the table 1

Table 1 : Terrain correction for low-frequency noise for wind turbines location onshore and offshore respectively, sound insulation (level difference) and air absorption coefficients per 1/3 octave at a relative air humidity of 80% and an air temperature of 10º C

1/3 octave centre frequency in Hz	10	12,5	16	20	25	31,5	40	50	63	80	100	125	160
ΔLgLF: ground correction, onshore wind turbine (dB)	6	6	5,8	5,6	5,4	5,2	5	4,7	4,3	3,7	3	1,8	0

ΔLgLF: ground correction, offshore wind turbine (dB)	6	6	6	6	6	5,9	5,9	5,8	5,7	5,5	5,2	4,7	4
ΔLσ: sound insulation (level difference) (dB)	4,9	5,9	4,6	6,6	8,4	10,8	11,4	13	16,6	19,7	21,2	20,2	21,2
αa in dB/km	0	0	0	0	0,02	0,03	0,05	0,07	0,11	0,17	0,26	0,38	0,55

5. NOISE EMISSIONS FROM WECS

A wind farm is formed with a certain number of WECSs, each of them can be taken as a point source of acoustic emissions, at the turbine hub height (in the present case 109 m). The main contribution in acoustic emissions of wind turbines is provided by the so called aerodynamic noise, induced by air flowing along blade airfoils. Such a noise has a wide band spectrum and is affected by the incidence angle of the relative air flow on blades (the airfoil of blade sections), and as a whole by wind speed. The gear adaptor, set between rotor and electrical generator, is a source of mechanical noise as well, but of tonal type, i.e. not restricted to a specific frequency range. In present WECSs nacelles containing electrical power generator and gears are efficiently shielded and given off noise is almost negligible if compared with aerodynamic noise. The electric transformer (accommodated within the turbine tower) can be easily shielded as it generates the typical noise of electrical equipment and is therefore negligible [12,13]. figure 3 and figure 4 shows the sound power levels for different wind speeds emitted by the WECSs considered in the present work. (VESTAS V112 2.5 MW PLATFORM). On the ground of what discussed before and since experimental data for sound power levels emitted in low frequency range are not available, we will proceed cautiously taking as sound power level for turbine emissions 110 dB

5.1 Wind turbines how noise Sources

The wind turbines here supposed as components of the wind farm are VESTAS V112 for a rated power equal to 2.5 MW. Wind power station includes 21 WECSs of such a kind. Data about sound emission ($L_{WA,ref}$) for the selected WECS are available in the data sheet provided by the manufacturer which contains emission levels, within the range from 10 Hz to 20kHz, measured for different wind speeds (Figure 3).

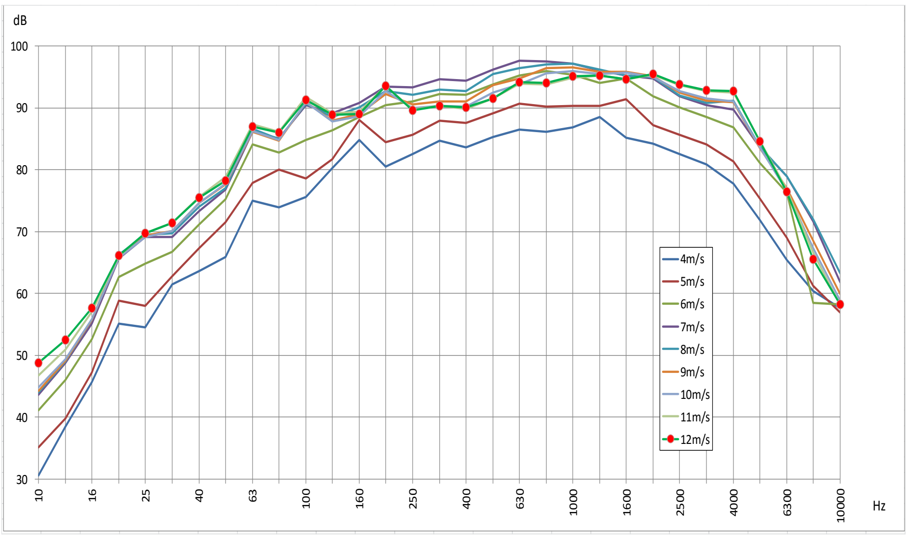

Figure 3. Sound power level emitted for different wind speed by WECSs

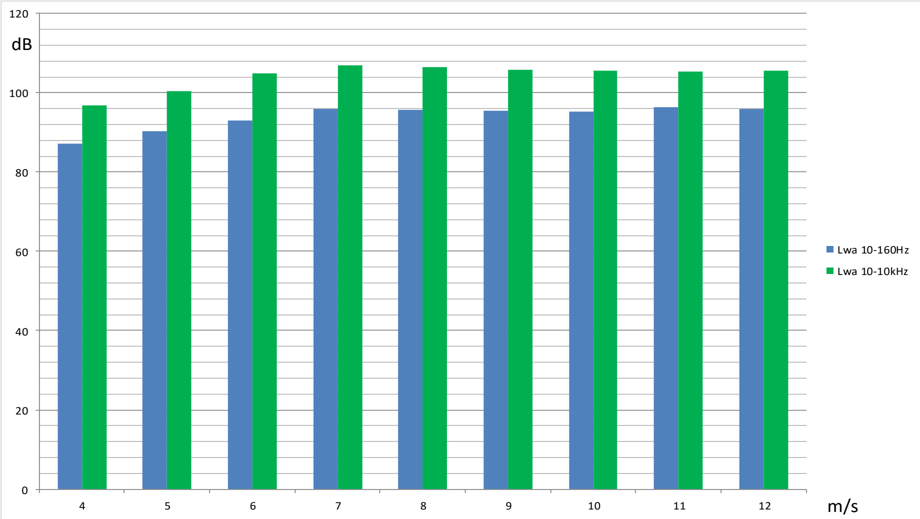

Figure 4. $L_{w,eq}$ in the infra sound frequency range (10-160Hz) and for the range (10Hz-20kHz) for different wind speed

6. CONCLUSIONS

The application of different computational models to a case study allows now to draw a conclusion. The calculation procedure based on the Danish norm leads to obtain sound pressure levels on average lower than those from UNI EN 9613 although the comparison is misleading in a measure. The coefficients for the low frequency (10Hz-160Hz) attenuation due to building envelope that have been used are not yet well established for the Italian construction types for which there are not standard curves so far. Following the main international researches, both in the engineering and the medical field, concerning low frequency sound waves propagation and their impact on human health, conflicting opinions can be deduced. However all studies agree upon asserting that there is no proofed and documented evidence about the damage to human health caused by the low frequency noise emitted by wind turbines. The results of present study confirm these evaluations.

Taking into account the calculation tools and the aid provided by prediction models , we believe that the impact of low frequency noise coming from wind turbines located nearby sensible receptors can be rated as negligible.

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