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Wind turbines noise measurements inside homes

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ABSTRACT

Wind energy is a primary source for achieving the objectives of the Oil Free Society. However, noise emission is often a significant problem encountered during wind turbines operation. Wind turbines noise generation is a complex phenomenon due to the effects of air interaction during the rotation of the blades. In this paper the noise measurements generated by the wind turbines inside some homes are reported. The wind turbines are installed on a flat area, at about 1000 meters above sea level, in a central area of the Apennines in Italy. The wind turbines (3 MW each) are located within a few hundred meters of the homes. Acoustic measurements were carried out with open windows for maximum disturbance condition and for different wind speeds and directions. The acoustic measurements were carried out when the towers were stopped and when they were in operation. In this way, the noise due to the operation of the wind towers was evaluated. The results of the incremental levels of the noise generated by the operation of the towers was measured to be an equivalent sound level (LeqA) of 20 dBA.

Keywords: wind turbines, noise, acoustic measurements.

I-INCE Classification of Subject Number: 25, 35, 51

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1. INTRODUCTION

Wind energy contributes significantly to reducing the use of fossil fuels in the production of electricity. It is a source of energy distributed throughout the territory, it does not produce fossil emissions, it does not consume resources already used by man and its installations occupy little territory. By comparing the net effects on the environment between the two sources of energy of wind and fossil fuels, the wind shows several advantages, although its intermittency [1,2]. Wind farms were initially realized in isolated areas, but continuous increased investments have led them to be expanded and built near to residential areas, thus creating for the residents in the surrounding areas noise pollution problems [3-6]. The first wind towers built for the transformation of wind energy into electricity were built in the United States in the 1950s and spread rapidly during the 1970s following the energy crises. Today, wind energy is the most competitive renewable energy source to produce electricity, with it both limiting the use of fossil fuels and reducing the effects of atmospheric pollution. It is, therefore, a rapidly growing market. In 1996, the global wind power accounted for around 6,100 MW; in 2001, it was 24,000 MW; while in 2017, it was about 540,000 MW. The highest yearly incremental installation peak was reached in 2015 with an installed global power of about 64,000 MW, with it slowly decreasing in 2016 (54.642 MW) and 2017 (54.492 MW). The areas with the most significant growth are Asia (with China and India), Europe (with France, Spain and Germany) and the United States. The first wind towers in Italy were built in 1990 and within a decade, there was a significant increase in the number of wind farms connected to the electrical distribution network. Due to both its geographical position as well as orography of the area, Italy has a significant number of possible of sites that are suitable for the installation of wind farms, especially in the southern areas and on the islands, where there are strong winds.

Most common wind towers have a horizontal axis with three blades and a nacelle (that rotates to face the wind) housing the gearbox and electronic equipment. The blades have a variable pitch, so that they can rotate around the radial axis to catch more or less wind, in this way it is possible to increase the electric production. Furthermore, for economy of scale reasons, wind towers are made with a nominal power and greater dimensions, with the nacelle often being about 100 m from the ground, and the blades with a diameter of about 100 m. This means that despite the rotation speed of the blades being very low, about 10-20 rpm, the point of the blade that is the furthest from the axis of rotation reaches a speed over 250 kilometres per hour.

Noise emission is one of the problems encountered during wind turbines operation. Wind turbines noise generation is a complex phenomenon due to the effects of air interaction during the rotation of the blades and the systems inside the nacelle [7 - 10]. The main noise components generated are: aerodynamic noise produced by the rotating blades (this noise tends to be broadband) and mechanical noise produced by the electromechanical parts (generator, turning over-gear, cooling systems and other components); this component has a sound level lower than the first and a few dozen meters away, is not perceptible.

Although the turbine noise is produced in the outer part of the blades [11,12], in the simulation of the external sound according to ISO 9613 [13], the wind turbine is considered as a point source, so in this hypothesis the total sound energy is issued near the gearbox. The sound pressure levels emitted by a wind tower increase upon increasing the electric power produced, even if the generated electrical power is low for wind speeds of 4 - 5 m/s [14].

When the blade passes near the tower (a passage occurs on average every second), a variation of sound level is generated, defined as amplitude modulation; the level variations are the most important factors in noise annoyance [15,16]. People describe noise as a variation of the perceived sound level, and show greater sensitivity "to modulated noise than to steady noise", and the effects of the amplitude modulations are the principal factor of the wind turbine noise. When compared to other noise sources, the degree of annoyance of sound from wind turbines is high. Major noise sources (road, rail, and air traffic, industry) in general do not cause severe annoyance below a sound pressure level of 40 dBA. At a sound pressure level of 50 dBA only 6% of the exposed residents are highly annoyed, whereas for wind turbines, severe annoyance occurs at lower levels below 40 dBA [17].

Sometimes when the wind speed is moderate, the noise emitted by the wind towers may be heard within a few hundred metres. However, when the wind speed is low, the noise emitted by the wind towers can be heard at distances of up to several hundreds of metres [18,19]. The aim of this work is to evaluate the condition in which the wind farm generates an annoying noise for people living nearby. People complain about a noise disturbance due to not excessive wind speeds. This work intends to investigate for which particular conditions the turbines generate an annoying noise. Despite the sound levels measured near the houses not being excessive since they are of the order of 40-50 dBA, people living near the towers are annoyed by the noise generated by the particular sound components.

In this paper the noise measurements generated by the wind turbines inside homes are reported. The acoustic measurements were performed under different weather conditions as well as with different wind speeds and directions. The same conditions were measured when the system was on and off. In this way, the noise increase due to the operation of the wind towers was evaluated. When the towers are off the measured equivalent sound level (LeqA) is about 30 dBA, while when the towers are operating the measured equivalent sound level (LeqA) is about 50 dBA.

2. METHODOLOGY

2.1 Characterization of the site and the wind farm

The chosen case study is an area with a wind farm that generates an annoying noise for people living nearby. People complain about a greater noise due to particular wind speed conditions. The site is located in Southern Italy, where there is wind all year round with an average speed of about 8-10 m/s; only on a few occasions does the wind speed exceed 25 m/s (exceeding this speed, the rotation of the blades is interrupted so as to avoid any possible damage) [20].

The wind turbines are installed on a flat area, at about 1000 meters above sea level, in a central area of the Apennines in Italy. The wind turbines are located within a few hundred meters of the homes. Acoustic measurements were carried out with open windows (maximum disturbance condition) and for different wind speeds and directions. The wind farm studied has eleven turbines, with each turbine having a horizontal axis and a nominal power of 3.0 MW. The towers are made of a single tubular post and a nacelle height of 90 m from the ground, equipped with three blades with a diameter of 112 m, average rotation speed 12 rpm.

Figure 1 shows the aerial view of the wind farm indicating the positions of the towers and the surrounding residential buildings.

The wind farm is located near the houses, with the land between the towers and the houses there few trees, since it is used to grow wheat. The prevailing wind is from a south-west direction. For short periods of the year, the wind comes from the north.

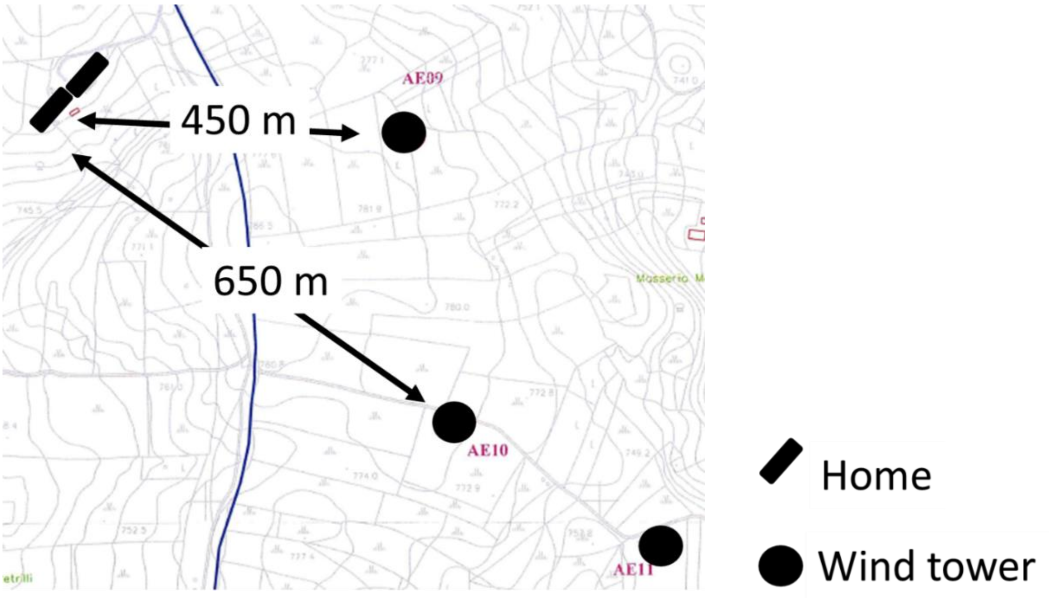


Figure 1. Aerial view of the wind farm showing the positions of the towers and the nearby residential buildings.

2.2 Measurement settings

The following instruments were used: sound level meter LXT1 Larson Davis of “Class 1”, calibrator Larson Davis CAL 200. The microphones had a diameter of ½”. The instruments used comply with the requirements of the standard IEC61672-2002. The sound level meters were configured to acquire the equivalent sound level of the linear sound, weighted “A”, of the statistical levels with a Fast constant time [21]. The sound level meter was placed on the west side of building.

The sound level meter was installed at a height of 1.40 m from the ground and 1.0 m from the window: the dimensions are 0.8 m in width, 1.5 m in height. The room in which the sound level meter has been placed has the following dimensions: 2.0 m in width, 3.0 m in length and 3.0 m in height. Only three towers are visible from the window of the room. The acoustic measurements were carried out with open window, which represent the maximum noise condition. The acoustic measurements were taken with the wind turbines both on and off, in order to evaluate, with the same wind speed, the noise contribution caused by the operating of the wind towers (ambient noise) as well as when they were off (background noise). Figure 2 shows the sound level meter during the acoustic measurements and the wind towers near buildings.

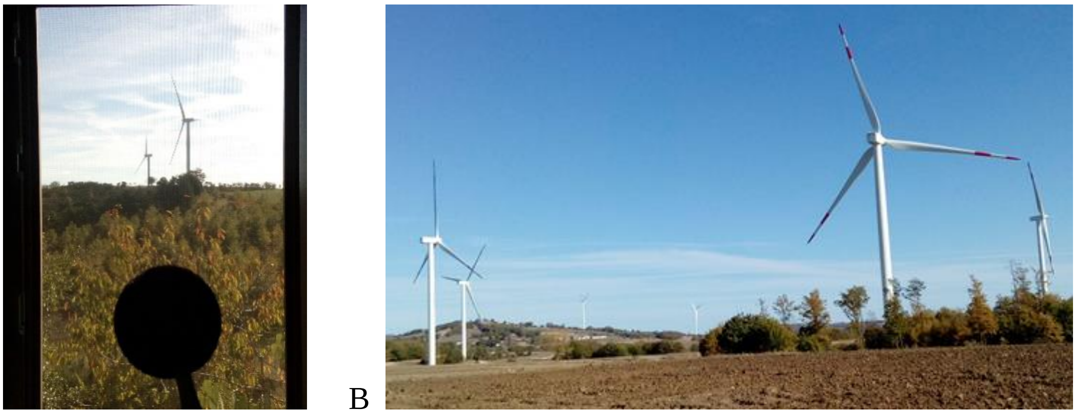
A  B

Figure 2. (A) Sound level meters during the acoustic measurements. (B) Wind towers near buildings

3. RESULTS

The noise measurements were taken during October with average wind speeds between 8 m/s and 10 m/s. During the acoustic measurements, a series of previously agreed upon starts and stops were carried out. The acoustic measures started at 9:30 and ended at around 21:00. They were performed both when the towers were in operation and when they were turned off. Figure 3 shows the time history of the sound pressure level during the whole measurement session.

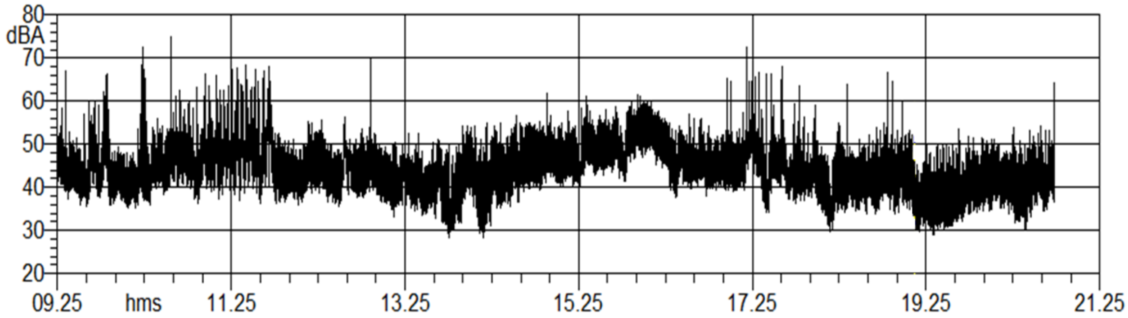


Figure 3. Time history of the sound pressure level during the whole measurement session.

The temporal history shows a fluctuating trend to mean that the sound levels have recorded more noisy conditions interspersed with quieter conditions. Since the surrounding environment has proved to be particularly quiet as no relevant anthropic activities were detected, it can be assumed that the fluctuations of the levels are due to the different operating conditions of the wind farm.

From the trend of the sound level in the diurnal period, it is possible to identify the period in which the towers are not in operation, and therefore to go back to the value of the residual noise. Furthermore, it is possible to evaluate the environmental noise value related to the condition in which the towers are operating. To do this the whole measurement period has been divided into intervals related to different operating conditions of the wind farm. Table 1 shows the values of the equivalent sound level weighted "A", the statistic level (L95) and the average wind speed for the different measurement intervals identified.

Time period	Towers On	LeqA (dBA)	L95 (dBA)	Average wind speed (m/s)
12.02 - 13.22	Yes	44.5	38.5	8 - 9
13.56 - 14.01	No	35.0	31.0	9 - 10
15.58 - 16.24	Yes	52.0	48.0	10 - 11
17.34 - 19.18	Yes	43.0	36.0	9 - 10

Table 1 - Summary of some descriptors measured in the identified time intervals

A first measurement interval has been identified starting from 12.02 and up to 13.22 for about 1 hour and 20 minutes. Figure 4 shows a time history of the sound pressure level during a fraction of the whole measurement session.

From these measurements it was not possible to evaluate either the residual noise or the background noise due to the impossibility of switching off the sound sources. Furthermore, the number of turbines in operation could not be precisely identified. In this time interval, the equivalent sound level weighted "A" measured was LeqA = 44.5 dBA, while L95 = 38.5 dBA.

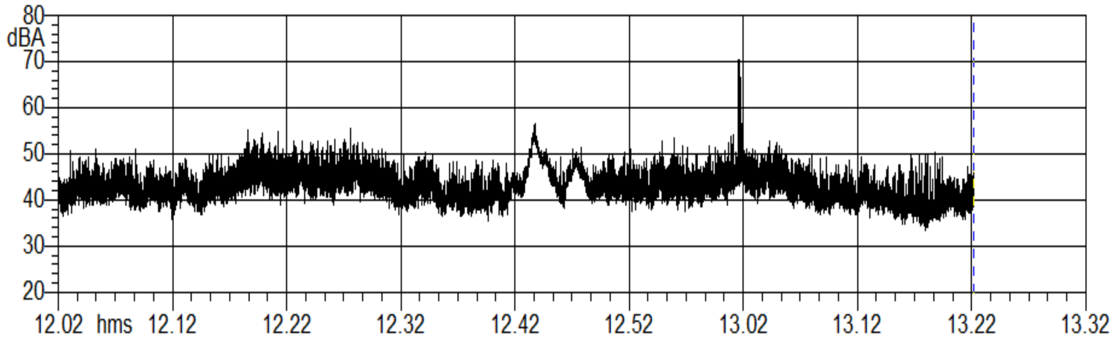


Figure 4. Time history of the sound pressure level from 12.02 to 13.22.

To characterize the measured noise a 1/3 octave bands analysis was conducted. Figure 5 shows minimum and average spectral levels in 1/3 octave bands between 16 Hz and 20 kHz. Minimum spectral levels in 1/3 octave bands are used to identify any tonal components. In this case no tonal components were identified. The frequency range at which the maximum sound emission was between 125 Hz and 500 Hz. At low frequencies, the noise is not generated by the towers. For frequencies above 500 Hz the sound level decreases.

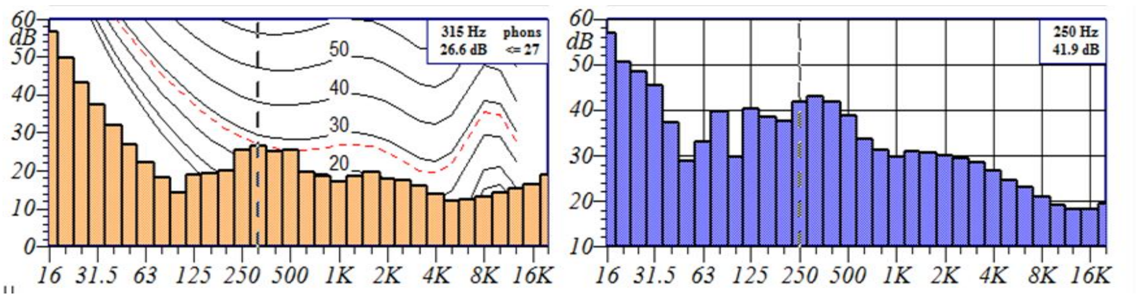


Figure 5. Minimum and average spectral levels in 1/3 octave bands between 16 Hz and 20 kHz.

A second measurement interval has been identified starting from 13.56 and up to 14.01. Although this measurement period is short, it is particularly significant. Figure 4 shows a time history of the sound pressure level during a fraction of the whole measurement session.

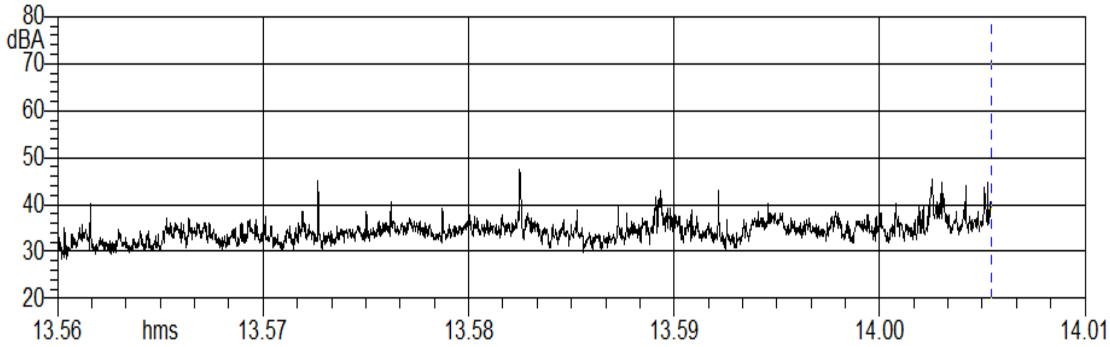


Figure 6. Time history of the sound pressure level from 13.56 to 14.01.

This interval is particularly significant as it corresponds to the condition in which all the turbines were turned off. In this way we were able to measure the background noise. In this time interval, the equivalent sound level weighted "A" measured was LeqA = 35.0 dBA, while L95 = 31 dBA. To confirm this 1/3 octave bands analysis was conducted. Figure 7 shows minimum and average spectral levels in 1/3 octave bands between 16 Hz and 20 kHz.

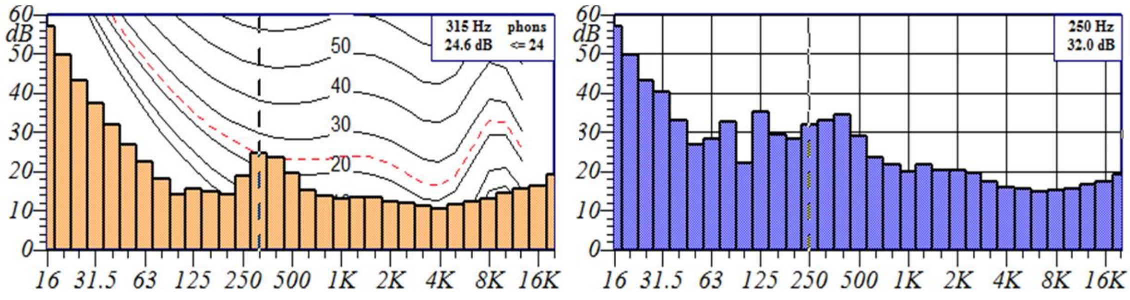


Figure 7. Minimum and average spectral levels in 1/3 octave bands between 16 Hz and 20 kHz.

Minimum spectral levels in 1/3 octave bands are used to identify any tonal components. In this case no tonal components were identified. At low frequencies, the noise is not generated by the towers. In this configuration the three towers in view from the window are turned off. In this configuration (in spite of the short time interval) it is possible to estimate the effects of the absence of noise due to the operation of the towers.

A third acoustic measurement interval has been identified starting from 15.58 and up to 16.24. In this period of operation all three towers were in operation. Figure 8 shows a time history of the sound pressure level during a fraction of the whole measurement session.

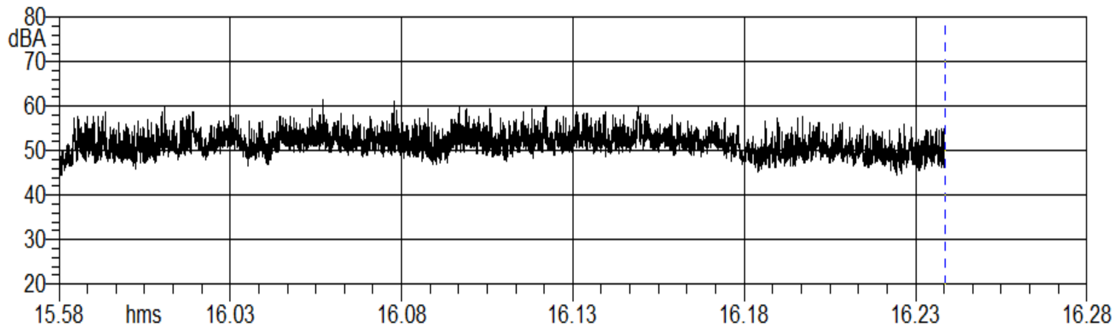


Figure 8. Time history of the sound pressure level from 15.58 to 16.24.

This time interval is the noisiest as all three turbines closest to the housing settlement have been in operation. In this way, we were able to measure the environmental noise. In this time interval, the equivalent sound level weighted "A" measured was LeqA = 52.0 dBA, while L95=48 dBA. To confirm the functioning of the towers, 1/3 octave bands analysis was conducted. Figure 9 shows minimum and average spectral levels in 1/3 octave bands between 16 Hz and 20 kHz.

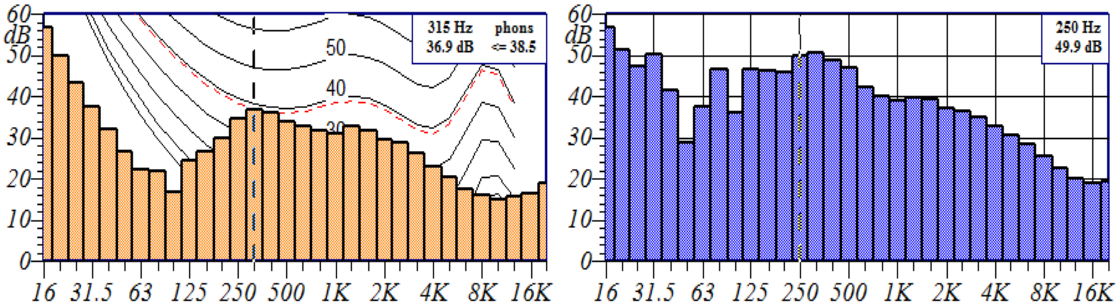


Figure 9. Minimum and average spectral levels in 1/3 octave bands between 16 Hz and 20 kHz.

Minimum spectral levels in 1/3 octave bands are used to identify any tonal components. In this case no tonal components were identified. The frequency range at which the maximum sound emission is found between 125 Hz and 500 Hz. At low frequencies, the noise is not generated by the towers. For frequencies above 500 Hz the sound level decreases. This condition is the most critical, although the acoustic measurement interval is about twenty minutes. The equivalent sound level LeqA = 52.0 dBA, while the value of the statistical level L95 = 48.0 dBA. The difference between this two levels is only 4 dBA, in this way there is a little noise fluctuating, which generates a sound level than 18 dBA compared to condition when the towers are turned off (time interval from 13.56 to 14.01). A final measurement interval has been identified starting from 17.34 and up to 19.18. In this period of operation some towers were in operation. Figure 10 shows a time history of the sound pressure level during a fraction of the whole measurement session. From these measurements it was not possible to evaluate the number of turbines in operation. In this time interval, the equivalent sound level weighted "A" measured was LeqA = 43.0 dBA. To characterize the measured noise a 1/3 octave bands analysis was conducted. Figure 11 shows minimum and average spectral levels in 1/3 octave bands between 16 Hz and 20 kHz.

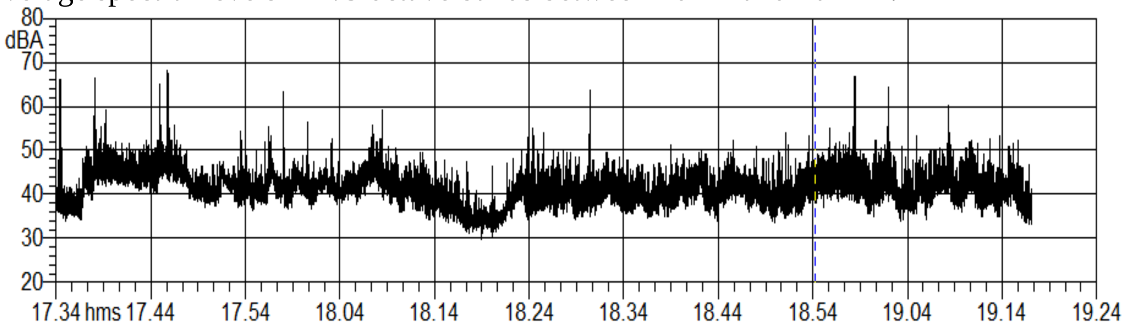


Figure 10. Time history of the sound pressure level from 17.34 to 19.18.

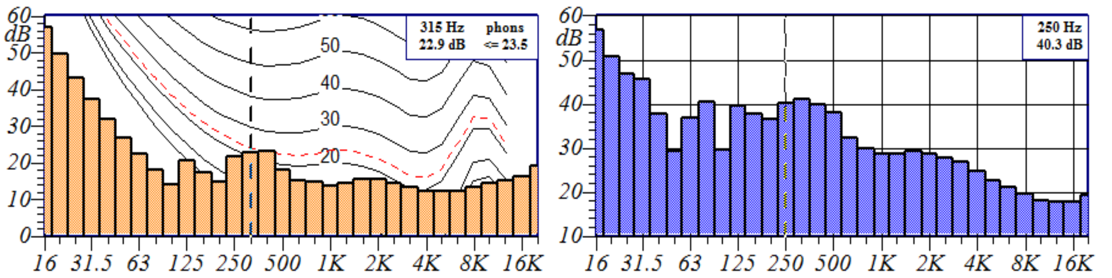


Figure 11. Minimum and average spectral levels in 1/3 octave bands between 16 Hz and 20 kHz.

Minimum spectral levels in 1/3 octave bands are used to identify any tonal components. In this case no tonal components were identified. The frequency range at which the maximum sound emission is found between 125 Hz and 500 Hz, as the sound level decreases above 500 Hz. At low frequencies, the noise is not generated by the towers.

The analysis of the results obtained with the measurements shows the following: The minimum emission condition corresponds to the sound pressure level equal to LeqA = 35.0 dBA identified in the second time interval identified. This condition represents the background noise. The condition of maximum sound emission corresponds to LeqA = 52.0 dBA identified in the third time interval identified, whihch represents the ambient noise. It is possible to establish that a difference of 18 dBA can be measured between towers on and towers off.

4. CONCLUSIONS

This work reports the results of acoustic measurements in the vicinity of a wind farm consisting of eleven towers, each with a capacity of 3 MW, but only three towers are visible from the house considered. The height of the hub of the towers is 90 m. They all have three blades with a diameter of 112 m, with a rotation speed of 10-20 rpm. From the analysis of the results obtained in the measurement session, characteristic time intervals of different operating conditions have been identified. In particular, it was possible to identify a time interval in which all the towers were turned off: This condition corresponds to the background noise. During this time interval a LeqA = 35.0 dBA (L95 = 31 dBA) was measured. Furthermore, a time interval was found in which all the towers were operating: This condition corresponds to the environmental noise. During this time interval a LeqA = 52.0 dBA (L95 = 48 dBA) was measured. In conclusion, between the conditions of towers on and towers off, there was a sound level difference of 18 dBA.

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