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SODAR wind measurements as a mean to refine acoustic analysis of wind projects.

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Abstract

Both background and turbine noise depend on wind speed. In rural environment, background noise is mostly influenced by the wind speed in the lowest parts of the atmospheric boundary layer, where the air flow interacts with vegetation and other obstacles. Conversely, turbine noise is related to the wind speed at hub height, which determines the operational conditions of rotor and electromechanical components. The IEC 61400-11 reports a reference roughness length of 0.05 m to account for wind vertical profile, linking wind speed at ground and hub height. In real cases, wind shear can differ considerably from these reference conditions, because of orographic effects and thermal stratification. In this work the use of remote sensing device like a SODAR is proposed as a mean to refine the acoustic analysis of wind farm projects. The SODAR can be easily transported and moved within the project site, and it can be used to measure the wind profile up to hub height. It is straightforward to discriminate the orographic effects such as speed-up across hills, and possible strong diurnal variability of the wind shear due to thermal stratification. A test case is proposed using real SODAR data, and the effect of the wind shear variability on the acoustic emission of a wind turbine is investigated. The resulting noise at a possible house is calculated in day/night cases. Both overall and differential noises are compared with the limits imposed by the Italian regulations, showing the role of the SODAR-detected wind shear on the accuracy of the acoustic analysis.

Introduction

In the early stages of wind energy development, wind projects could benefit of almost ideal sites, with excellent wind conditions and few environmental concerns. In many densely inhabited countries like Italy, the actual wind farm developer works through the maze of variable regulations and conditions, and the solution for a wind farm project has often to be found as a compromise between technical and environmental constraints. Among the latter, an important issue is that of the acoustic impact of wind turbines, which is growing attention as long as wind projects are closer and closer to villages or isolated houses in the countryside. In acoustic analyses, the first step which is typically performed is that of measuring background noise at possible

acoustic receptors like houses in the area of interest. In rural environment, background noise is mostly influenced by the wind speed in the lowest parts of the atmospheric boundary layer, where the air flow interacts with vegetation and other obstacles. Fageant et al. [1, 2, 3] have recently evidenced the dependence of background noise on wind speed, suggesting an analytical expression to represent such relation. Once the acoustic climate of the area is obtained by means of measurements, noise arising from wind turbines is estimated, typically through software simulation. When dealing with turbines, two aspects should be remarked: on the one hand, turbine noise depends on wind conditions at hub height, which influence the operational state of the turbine and hence its noise generation. On the second hand, in order to intercept stronger winds, modern turbines present higher and higher hub elevations, rising up to 100 – 120 m agl. This paper focuses on the relation between wind speed at ground and hub height, and its influence on the acoustic analysis of a wind farm. In particular, the role of a remote sensing device like a SODAR is investigated as a tool to achieve an accurate experimental evaluation of the wind vertical profile. The SODAR, lying on a car-truck, can be easily transported on site. After a brief (1-hour) configuration, the device starts emitting acoustic pulses on three tilted beams, and is able to reconstruct the wind vector with 5 m steps from 10 m agl to 150 m agl or more. After few days – weeks of operation, the recorded database can be used to derive the typical features of the wind vertical profile in the desired position. In particular, possible effects of site orography on the wind shear can be highlighted; furthermore, thermal effects can be evidenced, often resulting in clear variation between the diurnal and nocturnal wind shear. These features can have a significant operational meaning in terms of acoustic analysis, because many acoustic regulations require the calculation of diurnal and nocturnal shifts from background noise. The determination of accurate day and night wind profiles can therefore help to refine the acoustic analysis, evidencing possible critical conditions. In the present work a test case using real SODAR measurement is proposed.

Methods

A test case is reported in the following. The working hypothesis is that the installation of a wind turbine is proposed in a rural site, characterized by a farmland with open appearance and simple orography. The case of a Repower MM92 wind turbine is considered, having a 92 m rotor diameter; the hub height is hypothesized to be 100 m. A house is present in the near-by, thus being the only sensitive acoustic receptor. As in the aforementioned typical approach, the acoustic analysis starts with the evaluation of background noise at the house position. Here a typical noise from a rural environment is assumed, relying on [4], that is considering the following expression:

$$N_B = 10log_{10}\left(10^{\frac{k*log_{10}(v)}{10}} + 10^{\frac{b}{10}}\right),$$

In such equation, an increase of background noise with wind speed (*v*) at ground is assumed, because of the wind effects on surrounding vegetation, according to two parameters: b and k. With a typical choice for such parameters, the considered background noise at the site is reported in Figure 1.

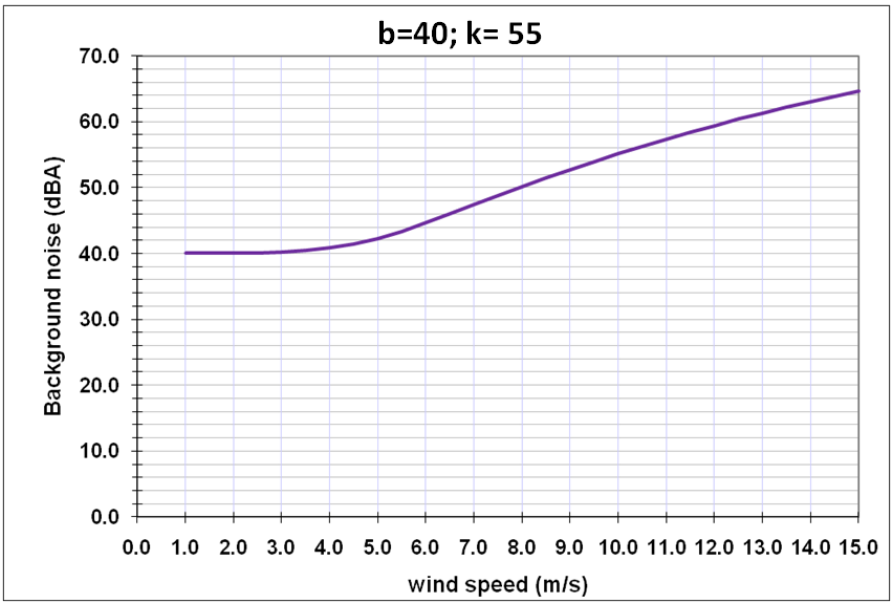

Figure 1 – Background noise assumed at the site.

To investigate the wind vertical profile, a SODAR device (AQ500 Wind Finder from AQSystem) is transported at the site, and set-up in the position where the wind turbine should be installed. It can be noticed that, given the simple orography of the site, the ground wind conditions at the whole area of interest, including the positions of turbine and house, are assumed homogeneous.

The SODAR device is kept working for few days-weeks. Then the measured wind data are elaborated to identify the experimental wind profile at the site, distinguishing between mean, day and night profiles. Such profiles are then used to estimate noise emission from the wind turbine, in the aforementioned cases plus a reference one, (exponential profile with $\alpha = 0.14$, as reported in the international standard IEC 61400-11 [5]). In other words, when a certain wind speed occurs at ground level (10 m), a different wind speed is calculated at hub height (here assumed 100 m) depending on the considered wind profile. In turn, different wind speeds at hub height correspond to specific noise emission of the turbine.

Finally, noise generated by the wind turbine is calculated at the house position, assuming a simple propagation model and a distance between them ranging from 200 m to 300 m. It is shown that, depending on site-specific wind shear, different acoustic results at the house are obtained.

SODAR measurements: experimental wind profile

Real SODAR data were used in this study, related to a measurement campaign in a simple terrain. SODAR transportability and placement are shown in Figure 2.

Figure 2 – SODAR transportation and set-up.

System set-up requires approximately 1 hour, and is needed to check the absence of undesired echoes related to possible surrounding obstacles. Once installed on site, the SODAR system starts delivering acoustic pulses on three tilted beams, by means of three parabolic antennas. The analysis of the scattered signal allows measuring the profile of the three-dimensional wind vector in the lower atmospheric boundary layer, from the height of 10 m up to 150 m or more.

Typical output of the device is a time series of wind speed and direction at the various measuring heights. It is straightforward to derive an average wind profile, as shown in Figure 3, related to about one month of data.

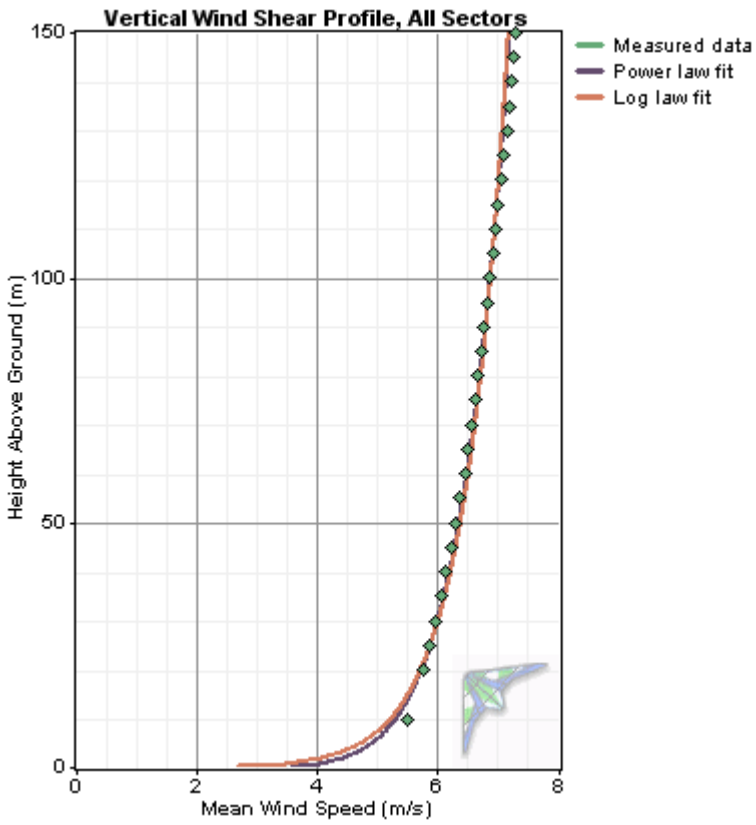

Figure 3 – Average vertical profile obtained by SODAR measurements.

The experimental measurements can be fitted through classical laws like Log and Power laws. The latter describes the wind shear as:

$$V(h) = V(h_0) * \left(\frac{h}{h_0}\right)^{\alpha} ,$$

where h_0 is a reference height and α the empirical exponent accounting for vertical dependence.

In the present case, a more detailed analysis of the daily pattern of the wind profile was carried out. The daily variation of the power law exponent is given in Figure 4, where each hourly value is obtained averaging about 200 vertical profiles in that specific time slot.

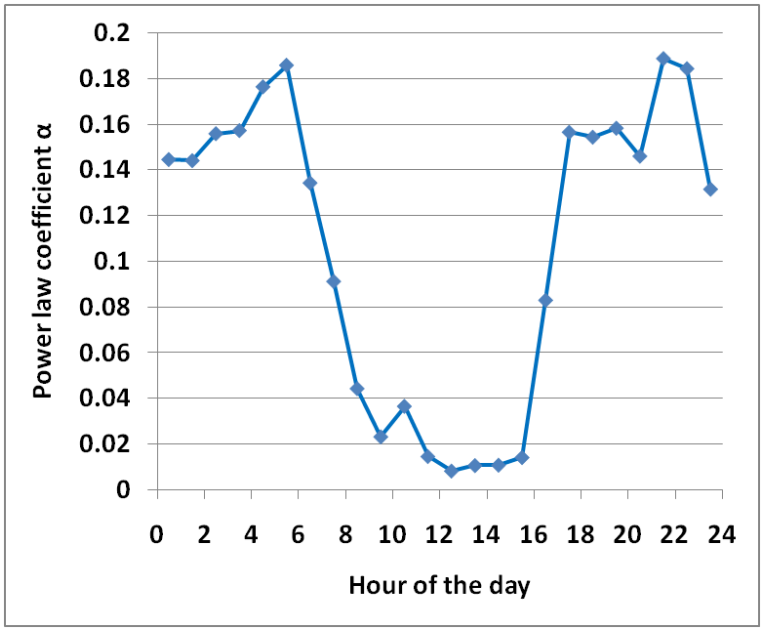

Figure 4 Daily pattern of wind vertical profile (expressed with power law exponent).

The daily profile reveals a strong variability of the wind shear: in the central part of the day, the high sun irradiation promotes ground heating and hence vertical mixing of the air flow. As a result, the α coefficient is significantly lower than during night time, where thermal stability is more frequent.

To characterize the measured daily pattern, the wind shear at the site was divided in 3 classes: mean profile, day profile (from 6 a.m to 10 p.m), and night profile (from 10 p.m to 6 a.m.). Such intervals are those indicated by the Italian regulation for acoustic analysis. The resulting profiles are reported in Figure 5, where the corresponding α coefficients are also reported.

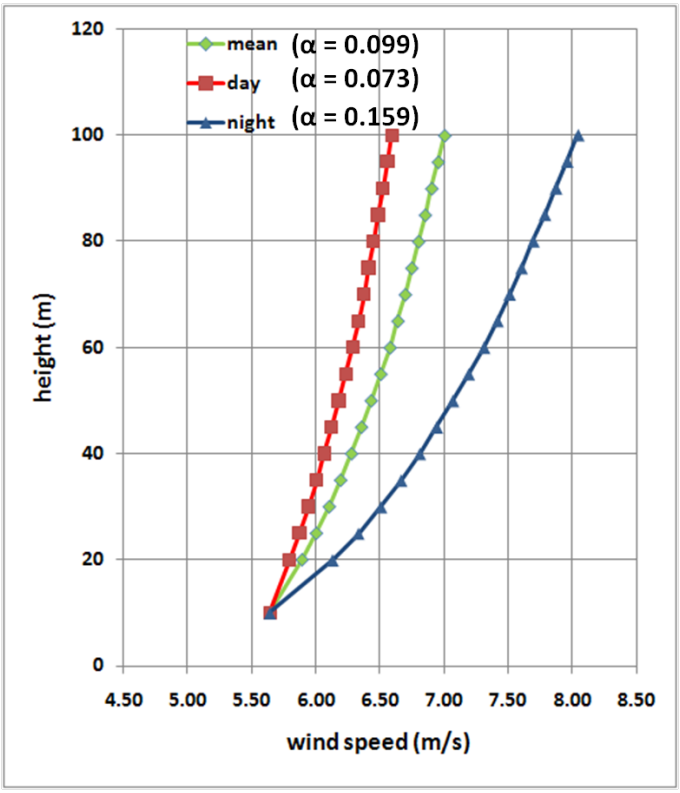

Figure 5 – Classification of the wind shear into mean, day and night profiles.

The remarkable variability of the wind shear between day and night is clearly shown in Figure 5. The corresponding α is about 0.1 if averaging over the whole day, while is reduced to about 0.07 in the day-time, an rises up to about 0.16 at night.

It can be stated that the observed behaviour, mainly due to thermal effects at the site, is typical of many Italian wind sites.

Linking wind profile with turbine noise emission

The calculated wind profiles can be used to relate wind speed at ground and wind speed at hub height, in the various identified cases. The acoustic relevance of this relation is straightforward: given a certain wind speed at ground, a different noise will be emitted by the turbine, depending on the existing wind shear. Indeed, the output noise depends on wind speed at hub height, and the latter depends on the wind shear. In this study the acoustic specifics of Repower MM92 were considered [6]. For the identified profiles, the corresponding sound power levels emitted by the turbine are reported in Figure 6.

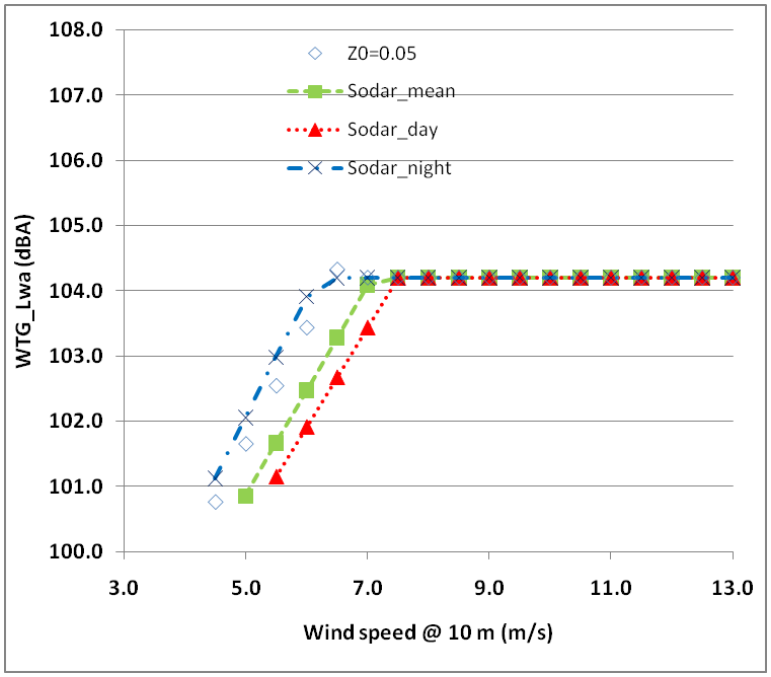

Figure 6 – Turbine sound power levels corresponding to different profiles.

It can be noticed that, for wind classes between 5-7 m/s at ground, the sound power level of the turbine will be higher at night than during the day, because of the higher α coefficient, and hence wind speed at hub height.

This can possibly lead to critical acoustic conditions: at night, when the background noise is low because of low wind conditions at ground, the nocturnal wind shear can make the turbine emit enough noise to overcome the differential limits.

Acoustic analysis: results of noise propagation

Finally, a simple propagation model was implemented to calculate turbine noise at the house position, assumed to be 200 m or 300 m away from the turbine. The propagation model is as follows [7]:

$$L_p = L_{wa} - 10\, log_{10}(2\pi r^2) - ar$$

where *Lwa* is turbine output power, *r* the house distance and *a* is an attenuation coefficient, assumed constant and equal to 0.005 dB/m. The model neglects any orographic effects in sound propagation, an acceptable assumption in the present simple-terrain test case.

The model was used to calculate turbine noise at the house, and then a logarithmic sum with background noise was performed, in order to calculate both total and differential noise at the house position.

In the case of 200 m distance between turbine and house, the noise results are reported in Figure 7, for the different considered wind profiles. In Figure 7, both total

noise (N_{tot}) and differential noise (Delta) are reported, and the differential limits of 5 dB and 3 dB are also indicated.

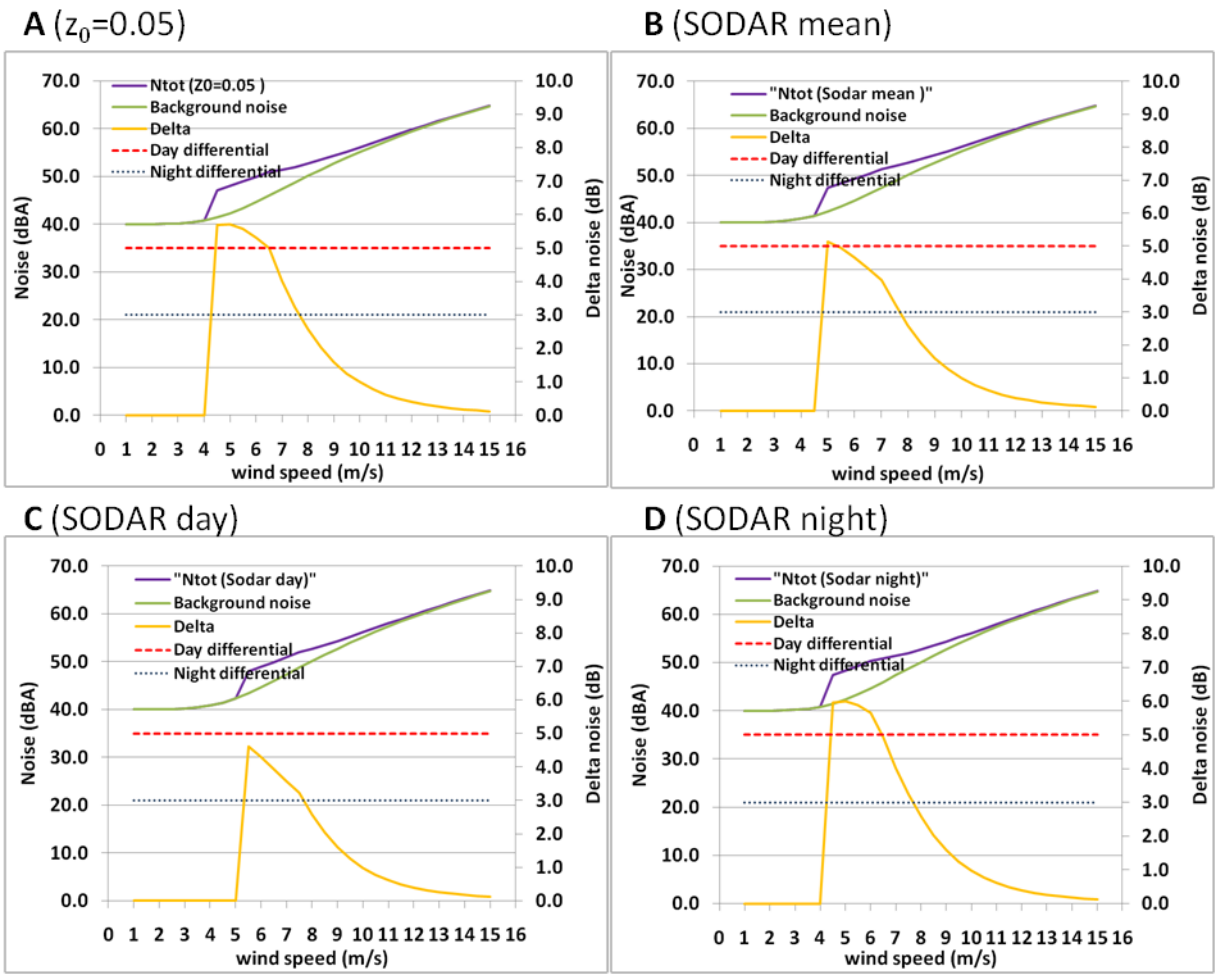

Figure 7 – Total and differential noise in the house position, at a distance of 200 m form the wind turbine. A, wind shear with z_0=0.05. B, mean wind shear calculated with SODAR. C, day wind shear calculated with SODAR. D, night wind shear calculated with SODAR.

Significant differences can be evidenced on noise results, depending on the considered wind profile.

When considering a z_0=0.05 wind profile (panel A), the differential noise Delta exceeds the limit of 5 dB for a range of wind speed (at ground). Conversely, if considering SODAR calculated profile, it is shown that during the day (panel C), Delta never exceeds 5 dB, because of the low α wind profile. At night instead, the differential noise Delta is always higher, and reaches 6 dB for given wind classes. Being 3 dB the night differential limit, this configuration shows therefore critical noise conditions at night.

When considering a greater distance (300 m) between house and turbine, noise results change according to Figure 8.

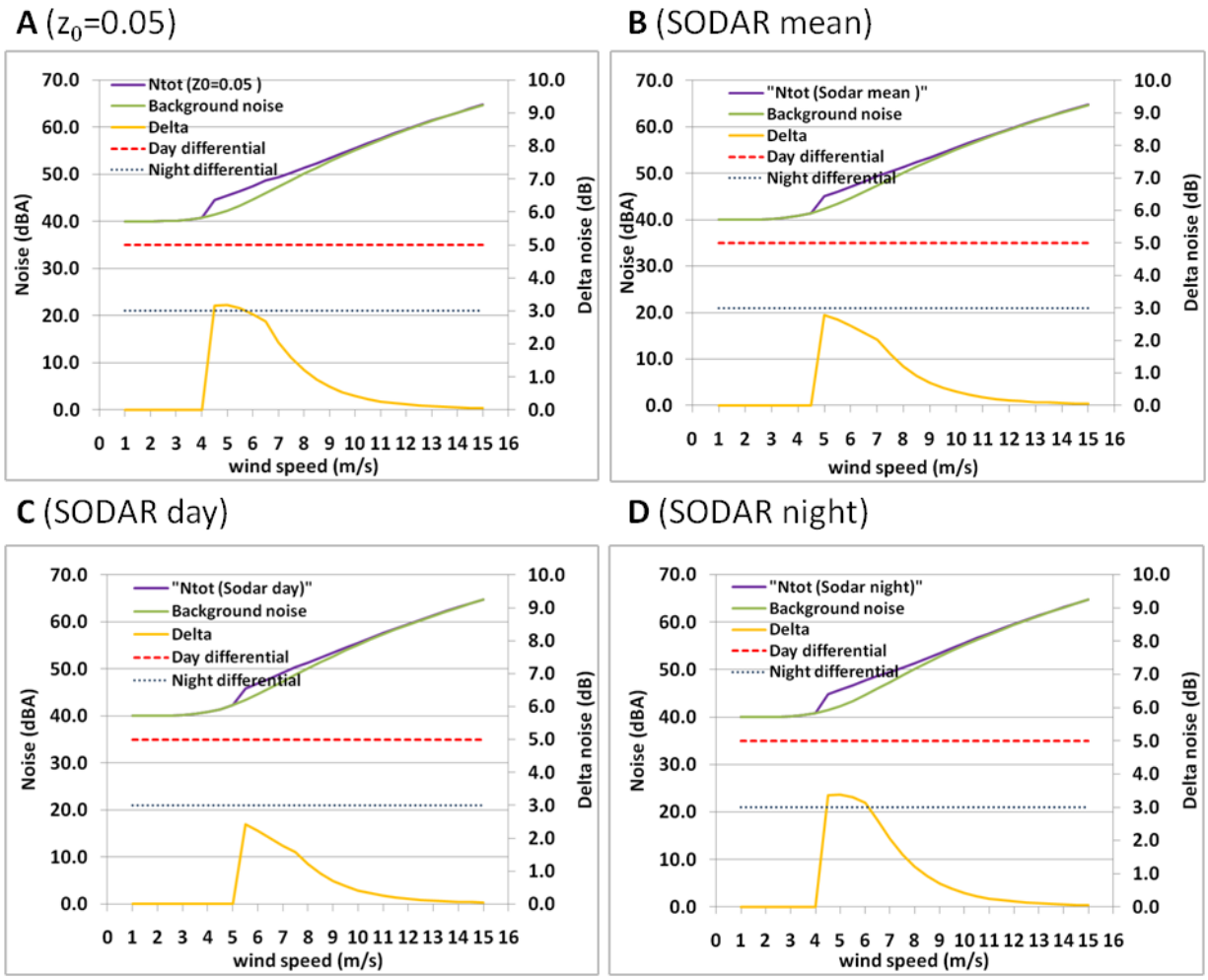

Figure 8 - Total and differential noise in the house position, at a distance of 300 m form the wind turbine. A, wind shear with z_0=0.05. B, mean wind shear calculated with SODAR. C, day wind shear calculated with SODAR. D, night wind shear calculated with SODAR.

Also in this case, noise results are dependent on wind shear.

In particular, if considering the z_0=0.05 and SODAR mean wind profiles (panel A and B), Delta nearly reach the 3 dB limit; when discriminating between day and night profiles (panel C and D), it is clear that, for a narrow range of wind speed, the 3 dB limit is exceeded, but only at night. In this case a slight nocturnal power control strategy would be sufficient to avoid the night limit to be exceeded.

Conclusions

In this work it is shown that, even in an easy test case with simple orography, thermal effects in the atmospheric boundary layer can induce significant variability in the wind shear, with a marked difference between day and night profiles. Therefore, given a certain wind speed (and background noise) at ground, a different wind speed will

occur at hub height, depending on the existing wind shear. Noise emitted by a wind turbine will correspondingly vary, thus affecting the both total and differential noise at a house nearby the turbine. The SODAR device, because of its simple transportation and set-up, proved to be a valuable tool to refine the acoustic analysis of a wind turbine, allowing to include wind shear effects. Further work will encompass real measurements of diurnal and nocturnal background noise during SODAR measurements, and also progressive complication of site orography. In complex terrain, the orographic effects on wind vertical profile can make the use of SODAR device even more attractive.

References

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