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Technical note

A procedure for the assessment of wind turbine noise

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ABSTRACT

The noise assessment at the receivers due to wind turbines in operation is usually performed through outdoor measurements. Background noise and wind turbines noise (WTN) are related to wind speed and both contribute to the overall measured noise levels (environmental noise). Nevertheless, the relation between noise and wind speed is not easily predictable, especially when the wind farms are installed in hilly terrains, where the wind shear is truly remarkable. In Italy and in other countries, this kind of assessment is even more difficult to perform due to the national regulations that require to compute the difference between environmental and background noise levels with the same weather conditions. Thus, to get a reliable and approved measure of the residual noise it would be necessary to turn off the wind farm. This work suggests a technical procedure to simultaneously estimate the immission and the residual noise components measured nearby a wind farm when the residual noise is mainly generated by wind. This allows the evaluation of the noise impact produced by operational wind farms, without requiring the farm shut down. The method aims to be fairly straightforward, thus maintaining the required scientific basis to be used as an assessment procedure by consultants and public bodies.

1. Introduction

Wind turbine noise (WTN) assessment presents particular aspects that distinguish it from other noise sources. Both the immission (WTN at the receiver) and the residual components of the measured noise levels are dependent on wind speed, therefore their identification using the results of any measurements performed when the plant is operational is difficult. The wind turbulence on the microphone surface [1], the residual noise from the other nearby sources, the vegetation and wind induced noise [2], are all effects hard to separate from the WTN. In some countries (e.g. Italy, France, U.K., New Zealand) such a separation of the contributions is required for the assessment of compliance with regulatory limits [3]. All the actual procedures require the plant to be temporarily shut down in order to measure the residual noise at several wind speed at ground height, with the consequent impact on the wind farm economic return. An additional problem is that the wind speed and its direction at ground level are affected by time and space variations not always related with the variations of wind at hub height, particularly in complex terrain [4,5]. A measure of residual noise can lead to an incorrect noise evaluation if it is performed: (a) in a different time period from the environmental measurement one; (b) simultaneously to the environmental noise measurement but in a site far from the receiver.

This note describes a specific procedure to estimate both the immission and the residual noise components measured outdoor at the receivers near a wind farm. The identification of the two components in the measured noise become possible on the basis of a three weeks measurement campaign of weather data and environmental noise, a phase of data cleaning from spurious events (anthropic and animals noise) and an iterative data analysis. This allows the adequate evaluation of noise impact produced by an operational wind farm without shutting down the plant. The procedure was conceived while working on the reorganization of the Italian WTN legislation, therefore its output was determined in order to comply with the Italian legislative and regulatory framework [6–8]. Modifications for the use in other countries are expected to be simple.

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2. Data acquisition and analysis

The procedure requires the acquisition of a set of acoustic and weather data from a 3 weeks measurements campaign. The 1 s time-history of noise level near the receiver is recorded with the microphone equipped with a 90 mm windscreen foam, in free field at 4 m height from the ground. Measurements are performed with the microphone positioned in the direction of the wind farm without obstacles and at a distance of at least 5 m from any reflective surfaces. The weather probe is placed 3 m above the ground ("ground height"), as close as possible to the microphone. The instrumentation for measuring sound pressure levels meets the requirements of a class 1 instrument according to IEC 61672-1 [9]. Each acoustic or weather measurement are integrated over consecutive periods of 10 min and the data affected by rainfall according to the Italian legislation are rejected, as well as those with duration shorter than 5 min after elimination of spurious data, such as human activities or animals noises. Data with wind speed at ground (v_{gr}) exceeding 5 m/s are significantly influenced by the residual noise generated by the wind and by the interaction of the microphone windscreen foam with the microphone itself do to wind turbulence [10], thus they are discarded.

3. Definition of the parameter involved

The inflow wind is the cause of the blades' motion and their rotation in a wind field generates noise in multiple ways [11]. The relation between the wind at the hub and the blade rotation speed (N) is not univocal on long term basis, leading to periods in which noise is not generated even if the wind is blowing. This is because the wind turbines stop when the wind speed is below the cut-in or is over the cut-off and because sometimes the wind turbines are forced to stop or rotate at reduced speed for maintenance, production or others operational needs. Moreover, due to the wind fluctuations in a large and complex area or due to the plant manager intervention, it is unlikely that in a wind farm all the turbines have simultaneously the same *N*. Therefore, the present procedure for noise assessment takes into account the relation between the noise emission and a new parameter that considers the different simultaneous N of all the disturbing turbines of the farm. The immission of WTN is associated to an *equivalent blades rotational speed* (N_{eq}) of the wind farm, which is directly related to all the different N values, rather than considering the wind speed at the hub height or the single N.

The N_{eq} parameter is defined according to the formulation suggested by the ISO-9613 standard for calculating the outdoor sound pressure level L_p at a distance d from a directional source with sound power level L_W. The total attenuation A [12] is due to the geometric divergence, the atmospheric absorption, the ground effect and other effects that are not relevant in the present model. The directivity of the source is considered to be related to the wind direction at the hub height ($D_{\theta,wind}$, where θ represents the wind direction). The sound power level L_W of a single wind turbine is set in the form $10\log N^{\beta}$, with β to be fixed, allowing therefore to estimate the sound pressure level due to the presence of the ith wind turbine at a distance d_i using Eq. (1), where k is a constant that takes into account the other attenuation effects that can be considered common to all the turbines.

$$L_{p,i} = 10\log N_i^{\beta} - 10\log d_i^2 + D^i_{\theta,wind} + A^i_{atm,ground}(d_i) + k \tag{1}$$

The overall WTN level from the whole wind farm at receiver is given by the sum of each single WTN of the farm:

$$L_p = 10\log\left(\sum\left(\frac{N_i^{\beta}}{d_i^2}\cdot 10^{\frac{D^i_{\theta,wind}+A^i_{atm,ground}}{10}}\right)\right) + k \equiv 10\log\left(\frac{N_{eq}^{\beta}}{d_1^2}\cdot 10^{\frac{A^1_{atm,ground}}{10}}\right) + k \tag{2}$$

In Eq. (2) the overall WTN level at receiver depends on a single parameter of the farm, the N_{eq}, which represents the rotational speed of a single "virtual" turbine generating the overall noise pressure level of the whole wind farm. The virtual turbine is placed in the position d_1 corresponding to the closest turbine to the receiver. Following Eq. (2), the N_{eq} can be defined as:

$$N_{eq} = \sqrt[\beta]{\sum_i\left(N_i^{\beta}\cdot\left(\frac{d_1}{d_i}\right)^2\cdot C_i^{\beta}\cdot K_i^{\beta}\right)} \tag{3}$$

$$C_i = 10^{\frac{D^i_{\theta,wind}}{\beta\cdot 10}}, \quad K_i = 10^{\frac{A^i_{atm,ground}-A^1_{atm,ground}}{\beta\cdot 10}} \tag{4}$$

C_i can be seen as a directivity correction depending on the difference in wind direction between the ith turbine and the nearest one. It also includes the meteorological effects on sound propagation, as it will be discussed in the following section. K_i takes into account the combined effects of ground attenuation and air absorption. These parameters can be expressed as in (4). In this way, the problem of multiple turbines is transformed in a simpler single virtual wind turbine that generates at receiver the equivalent noise level of all the impacting turbines. The virtual turbine is placed in the position of the closest turbine (d_1) and its blade rotational speed is N_{eq}.

The full definition of the N_{eq} is completed by defining the source parameter β, the attenuation term $A_{atm,grond}$ and the correction $D_{\theta,wind}$.

The broadband trailing edge noise is the dominant WTN source [13]. It is generated in the outer part of the blades and, for most of the turbine models on the market, its power scales with the fifth power of the local flow speed. Also the inflow turbulent noise and the tip noise are other important mechanism of noise generation that scales with similar trend [14–16]. The blades rotational speed (N) is the most important parameter affecting the noise emission [17] and the wind speed incoming on the blades is generally linearly related to N [13,18,19], also when looking at the immission noise at receiver far from the sources [20]. Thus, for the purpose of the procedure, in the first step β can be set equal to 5. At the end, the procedure may be repeated taking into account the specific trend obtained with the first run and then selecting a more suitable value for β. It can be shown that set the exact value for β is not a critical point in the procedure.

According to the ISO 9613, the air absorption is a function of frequency, temperature and humidity. The ground attenuation depends on the elevation profile, on the ground typology and on the distance. It is possible to combine them in a single attenuation term linearly dependent on distance $A_{atm,ground} = -\alpha\cdot d$.

Different α were estimated for both flat and complex terrain by means of a Monte Carlo Method (MCM) applied using the ISO 9613 as noise propagation model to a generic WTN power spectrum [21], considering also the temperature, the humidity, the hub and receiver heights and the ground factor as variables. The average value of the alpha distribution for flat terrain, rounded to the first integer, is α = 3 dB/km, while for hilly terrain, considering the average over various random altitude profiles an average value of α = 5 dB/km is obtained. $D_{\theta,wind}$ considers the influence of wind direction and meteorological effects as wind and temperature gradients in the propagation of noise by means of Eq. (5):