EURONOISE 2006
30 May - 1 June 2006 Tampere, Finland

MAPPING NOISE OF WIND-FARMS (N°400)

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ABSTRACT

This paper describes a model which has been developed and used for wind mapping adapted to wind-farms. It differs from the conventional models of specular reflection in that it is based on the assumption that the sound waves are diffused on their reflection by the ground. The meteorological characteristics are defined by temperature and wind speed changes at height. The orientation of the wind is also taken into account and is assumed to be constant at the height covered by the calculation. These characteristics enable the speed of sound propagation with height to be evaluated and the sound wave refraction to be deduced. The sound wave curve is evaluated. When the curved sound waves come into contact with the ground (taken into account with its topography by the model) or any other type of obstacle, the model evaluates the diffraction and the sound energy which result. Ultimately, the model allows the noise map to be plotted for complex topographies in both good and poor airborne noise propagating conditions (upwind and downwind). Measurements and calculations have been carried out in real situations and we describe them in this paper.

1 INTRODUCTION

In France, the noise impact of wind turbines is measured by what is called the “sound emergence”. This measured value must not be exceeded. Noise impact studies have to make predictions in order to ensure that this limit is not exceeded and if necessary indicate to wind farm developers how their projects can be modified to satisfy this requirement. These modifications often consist in decreasing the number of wind turbines in operation if the weather conditions would cause the legal limits to be exceeded. Therefore these conditions have to be identified as closely as possible.

Weather conditions have an impact on sound propagation and are one of the parameters which influence this “sound emergence”. The noise level may vary considerably upwind and downwind of a noise source. The models used for the impact assessment should take into account the weather conditions which are least propagators of noise emissions so that the operation of the wind turbines can be adjusted to suit these conditions. Thus, models which are defined for airborne noise emissions only (such as ISO 96-13) are not sufficient to cover these particular site characteristics. Moreover, in France, wind turbines are often installed on hilly terrain. The models must therefore take into account the influence of topography on sound propagation.

This paper describes results obtained using a model which has been developed and applied to operational forecasting for with wind farms (short calculation, time, noise map plotting, etc.)

It differs from the conventional models of specular reflection in that it is based on the assumption that the sound waves are diffused on their reflection by the ground. This aspect of the model is described in references [1]

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These characteristics enable the speed of sound propagation with height to be evaluated and the sound wave refraction to be deduced. This enables the sound wave curve to be evaluated. When the curved sound waves come into contact with the ground (taken into account together with its topography by the model) or any other type of obstacle, the model evaluates the diffraction and the sound energy which result.

Ultimately, the model allows the noise map to be plotted for complex topographies in both good and poor airborne noise propagating conditions (upwind and downwind). Measurements and calculations have been carried out in real situations and we describe them in this paper.

2 THE REFRACTION INFLUENCE

In the context of a wind turbine impact study, we seek to calculate the noise levels far from the sources. Any changes in the characteristics of the atmosphere will have an influence on the result. Two phenomena are to be taken into account:

- The change of sound velocity with altitude leading to the refraction of the sound waves

- The absorption of sound by the atmosphere

This latter point is included in our model, as proposed by standard ISO 96-13 Part1. Thus we will not expand on it further here and will examine the refraction phenomenon.

The variation in the temperature and the wind speed with altitude induces a celerity change with altitude which leads to refraction of the sound waves propagated in the atmosphere. This well-known phenomenon leads to curvature of the sound waves. There are complex models for solving the parabolic approximation of the Helmoltz equation which translates acoustic wave propagation (FFP, PE, GF-PE, Split-step Padé, LE and Lagrangien Model) exist. They are expensive in calculation time and cannot be easily adapted to operational applications such as ours. This is part of the geometrical acoustic approximation. In our case, it consists in determining[1] the trajectory of the "ray" of sound. This results from the integration of the classic following equation:

$$\frac{dz}{dx} = \frac{c(z)\cos i(z)}{c(z)\sin i(z) + U(z)} \qquad (1)$$

where, C(z) is sound's celerity et U(z) wind's speed, at the height z.

The trajectory is curved and the curvature is oriented towards the ground or towards the sky. In the latter case, from a certain distance there would no longer be any acoustic energy coming from the source (shadow zone). However, experience has shown the existence of energy in this zone. Several factors explain this acoustic irrigation of the shadow zone (presence of turbulence in the atmosphere which diffuses the sound energy, diffraction of sound waves by the ground, etc.)

At present, our model takes into account this shadow zone irrigation phenomenon by the diffraction of the sound wave on the ground and by diffusion of the sound energy striking the ground.

It is to be noted that, in cases of complex topographies and meteorological environments, the equation for the trajectory (figure 1) becomes:

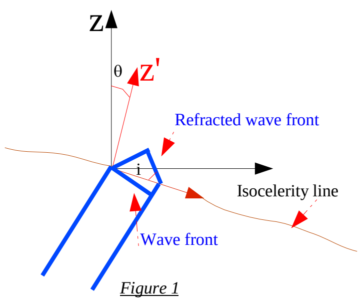

Figure 1

$$\frac{dz}{dx} = \frac{U(z)\sin(\theta+\alpha)+c(z)\cos i(z)}{U(z)\cos(\theta+\alpha)+c(z)\sin i(z)} \qquad (2)$$

With

- θ is the angle of the isocelerityline to the horizontal
- α is the angle of inclination of the wind speed to the horizontal

[1] And use of this trajectory in the model presented in reference [1]

3 COMPARISON OF THE CALCULATED RESULTS WITH MEASURED RESULTS

In this paper, we present the results obtained on three different wind farm sites. An impact study type of approach has been used to measure the noise level. The purpose of this approach is not to detail its thoroughness[2]. These results are meant to be representative of the noise level generated by the wind turbines alone (i.e. corrected for background noise).

3.1 Site 1

This is a rural site with bush and tree vegetation.

There are six wind turbines on this site (80 m hub height). The ground is to be modelled in the form of a plane (maximum level difference of about 30 m at a distance of 500m). The mesurement points around the wind turbines are between 300 and 1220 m away.

The results of the measurements (which will be compared with the computed results) correspond to a period of nighttime operation with a south-westerly wind and a mean wind speed of 2.7s at 10 m above the ground. The average temperature during this period is 9°C.

The following table gives the computed results obtained compared with the measured results.

Table 1. Computed results for site 1

	Level dB(A)		
Points	Measu.	Our calcul	Calc. ISO 96-13
1	25	25	20
2	--	24	19.2
3	26	22.5	17.4
4	--	22	--
5	29	27	--
6	28.5	26	--
7	29	30.5	--
8	25	29.5	24.6
9	--	27	21.6
10	33.5	35	28.8
11	38	38.5	34.4

The noise level generated by the wind turbines at points 2,4 and 8 is drowned by the background noise observed. For information, Leq1mn values between which the background noise fluctuated are

- point 2: 32 to 39 dB(A)

[2] The difficulty of measuring the impact of a wind farm is associated with the fact that the noise generated by the wind turbines is often drowned in the background (caused by the wind). The measurement procedures used in France are becoming standardized. A draft standard is currently being prepared. The procedures used for taking the measurements as described in this paper are in line with this draft standard.

- point 4: 38 to 46 dB(A)
- point 9: 28 to 38 dB(A).

A comparison of the measured results and the computed results shows good concurrence

Morever, for the points to wich ISO standard 9613-2 applies (ie.points with downwind sound propagation), the table shows the results obtained with this standard. The comparison of these results with the measured results shows that they are underestimated by the noise level standard. Therefore, this standard is not suitable for modeling wind farms on flat sites.

3.2 Site 2

This is a rural site with bush vegetation.

There are eight wind turbines on this site (40 m hub height). The turbines are situated on a crest and the relief is broken. The specific characteristic of this analysis is that the measurements, which we made, always showed that at distance greater than 900 m from the wind turbine line the noise generated by the wind turbines is drowned in the background noise. However, one point concerning the validation of this calculation model appears interesting to us. The image below schematises the wind turbines (red points) and this point of reception:

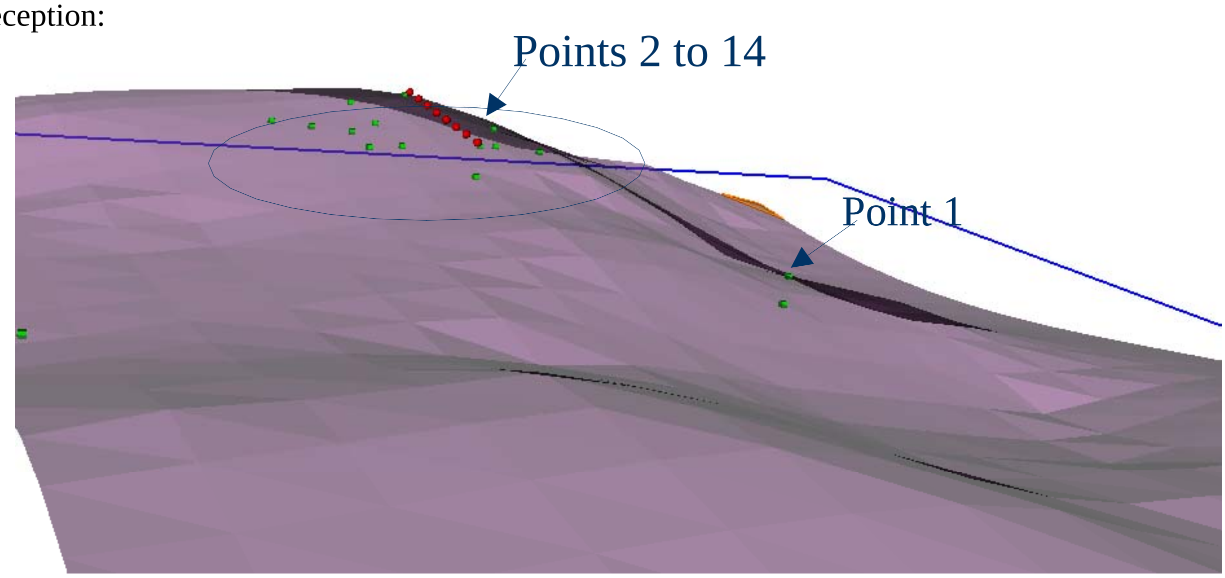

Fig. 2. Site 2

This point is interesting in that it is critical with regard to the combined influence of the topography and refraction. It is located at a lower level (approximately 250 m lower), and a distance ranging between 1000 and 1500 m from the wind turbines. The wind turbine line is not directly visible from this point. However, the noise generated by the wind turbines is slightly audible, whereas the noise level in dB(A) is not impacted by the operation of the wind turbines. This means that the noise of the wind turbines alone is less by several dB(A) than the measured noise level, but the audibility means that the difference between the wind turbine noise alone and the measured noise is less than 10 dB(A). A calculation which does not take into account the influence of refraction but takes account of masking by the topography gives a noise level 20 dB(A) less than the measured noise level at this point. Therefore refraction obviously has an impact at this point.

The measurement results with which we compare the computed results cover a nighttime period with a west-north-west wind at a mean wind speed of 6 m/s 10 m above the ground. The average temperature during this period is 18°C.

The noise level in these conditions is slightly above 30 dB(A), whether the wind turbines are operating or not.

The noise level obtained by calculation is between 25 and 28 dB(A) (depending on the precision of the topographical modeling). This corresponds to expectations. Standard ISO 96-13 is not suitable for this type of configuration either (see table below: point 1).

The table below recaps this result with those obtained at the other points (less than 900 metres from wind turbines).

Table 2. Computed results for site 2

	Level dB(A)		
Points	Measu.	Our calcul	Calc. ISO 96-13
1		25 à 28	--or 13(1)
2	36.5	41	--
3	45.2	45	--
4	40	42	--
5	39	43	--
6		46	--
7	39	40.5	39.5
8	37.5	38.5	37
9	43	44.5	44.5
10	42	42	41
11	45	45	--
12	40	43	--
13	48	50	--
14	51	53	--

(1)13 if ground considering like a screen

3.3 Site 3

This is a rural site with bush and tree vegetation.

There are 21 wind turbines on this site (40 m hub height). As with site 2, they are on a crest and the relief is broken. The level difference between the highest wind turbine and the lowest point of reception is approximately 200m.

The distance between point 1 and the wind turbines is between 600 and 2100 m, 1600 and 2100 m between point 2 and the wind turbines, and 700 and 1500 m between point 3 and the wind turbines. There is a pine forest close to point 1 which masks the wind turbines from this point.

The measurements compared with the computation results correspond to nighttime operation with a north-east wind at an average wind speed of 6m/s 10 m above the ground. The mean temperature during this period is 10°C.

The following table shows the computed results obtained compared with the measured results.

Table 3. Computed results for site 3

Points	Level dB(A) Measu.	Our calcul	Calc. ISO 96-13
1	29	36	--
2	33.5	35	32
3	39	41	40

At present, our model does not take into account the influence of an attenuation due to crossing a forest. This is most probably the cause of the difference between the calculations and measurements at point 1. It is an improvement to be made. At the two other points, the comparison of the measured results with the calculated results show relatively good concordance.

4 CONCLUSION

The model that we have presented in this paper can be used to assess the noise impact of wind turbine farms by accurate calculations which match the accuracy of measurements and take account of the main factors that influence sound propagation over long distances. These factors are atmospheric absorption, refraction, diffusion and diffraction on the ground, and topography.

This model is sufficiently operational to allow dimensioning of scenarii in the context of wind turbine impact studies, and to plot useful sound maps for communication to residents living close to wind turbine farms. Moreover, it is better suited to the calculation of wind farm impact than the one proposed by standard ISO 9613-2.

SOMES REFERENCES

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