Dispersal of measured sound power levels for wind turbines

René Gamba and Sébastien Garrigues

Gamba Acoustique, 2 rue de la découverte, BP 163, 31676 Labege Cedex, France
rene.gamba@acoustique-gamba.fr

Abstract

The standard IEC 61400-11 provides guidance in the measurement, analysis and reporting of acoustic emissions (sound power levels) from wind turbine generator systems. The application of this standard aims to provide accurate results that can be replicated by others.

We did several measurement operations according to this standard on various wind farms fitted with many turbine manufacturers on different ground types. Important differences (up to 10 dB(A)) have been noticed with equal working conditions between the most and the less noisy wind turbine on a single farm.

We will present these results compared to the manufacturers' guaranteed values and initiate explanations (like the influence of wind incidence on blades, wind turbulences or component defaults).

Introduction

For modelising the noïse emmitted from windturbines fields, we have to take into account different sound parameters acting on the acoustic wave propagation between the source and the sensor [1] [2] [3].

The result of modelisations depends on the acoustic power of machines (input data of the problem), the error on this reult will be directly linked to each error or uncertaintity introduced on the calculations. This data is well defined on the manufacturers' guaranteed values certified by specific measurement on machines.

In order to analyse the sound impact of a windturbines field, we make the hypothesis that each windturbine has the same acoustic power level, cause they are similar and are working with the same wind characteristics. We take the manufacturers' guaranteed value. However, no uncertatintity is referenced, but we know that there is a dispersion on real values of acoustic power for each winturbine of the same field.

No measurement on this point was made, that's why we decided to make these measurements on each machine on different windturbines fields.

These measurements show important dispersion between same type of machines on the same field. The data certified by the builder where more important for different cases.

This result shows that we can obtain bad modelisation results if we don't take this parameter into account.

In order to begin the research for explaining these dispersions of sound emmision, we'll analyse the differents sources of noïse of a windturbine.

Measurement of the acoustic power of a windturbine

This value of the acoustic power depending on the wind speed is a data well known an defined by specific measurements described by a convention.[4].

The main goal of this convention is the comparison of measurements on the same type of machine, but on different plants. For that, lot of parameters are defined :

- Location of the measurement
- Speed of wind
- Extraction of measurement data
- Method to analyse measurements and calculations.

Finally, we obtain our acoustic power data with wind speed measured at 10 meters of the floor for a standard ruggedness (equivalent to a flat floor, full of grass).

Study of acoustic power of machines on different windturbine plants

Presentation of measurement results

We've measured acoustic power of all windturbines of different plants. The measurement protocol is defined on the convention [4].
Machines measured are made by different manufacturers and their electric power ranges from 850 to 2500 kW. The ruggedness of the different fields studied are quite different (flat to rugged).
For each field, we show the acoustic power curves obtained for each machine, with the characteristics of windturbines and fields.

Field 1
Land-surveying : flat fields, a few of big trees, cultivated fields.
Type of windturbines : 1600 kW, hub heigh : 70 meters

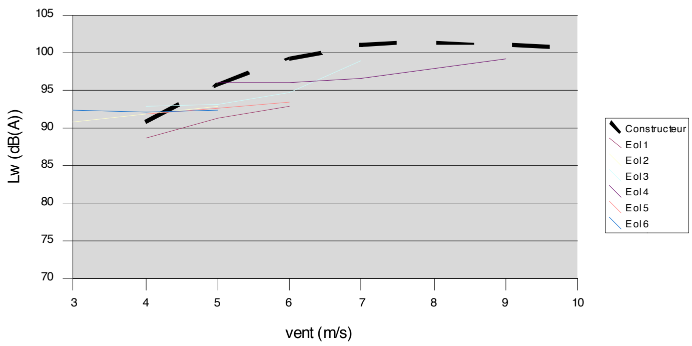

Figure 1 Comparaisons of acoustic power of machines _ Field 1

Field 2
Land-surveying : flat fields, some trees, cultivated fields.
Type of windturbines : 2000 kW, hub heigh : 80 meters.

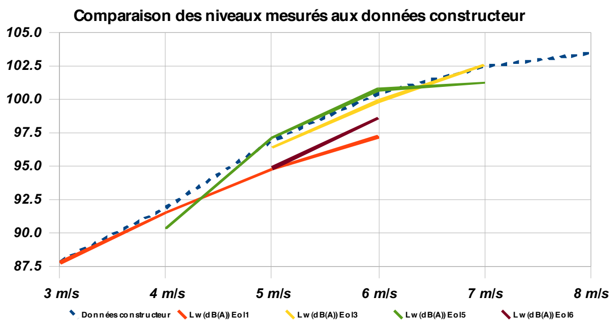

Figure 2 Comparaisons of acoustic power of machines _ Field 2

Field 3 :
Land-surveying : rugged fields, some vegetation, cultivated fields.
Type of windturbines : 850 kW, hub heigh : 55 meters

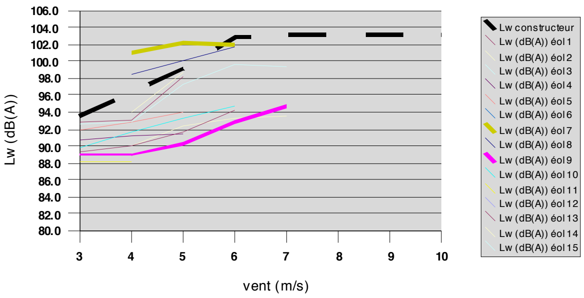

Figure 3 Comparaisons of acoustic power of machines _ Field 3

Field 4
Land-surveying : rugged fields, some vegetation, cultivated fields.
Type of windturbines : 850 kW, hub heigh : 55 meters

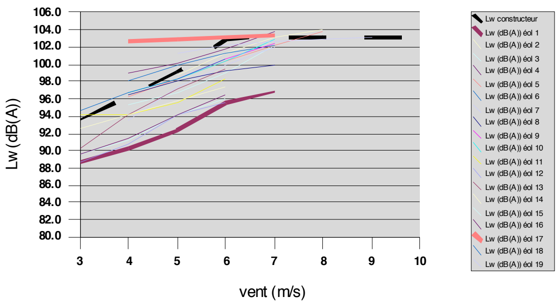

Figure 4 Comparaisons of acoustic power of machines _ Field 4

Field 5
Land-surveying : flat fields, a few of vegetation, cultivated fields.
Type of windturbines : 2500 kW, hub heigh : 80 meters

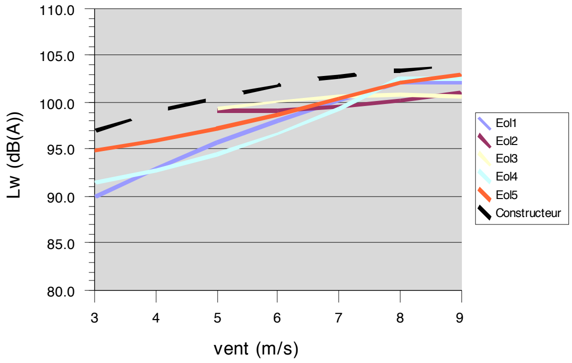

Figure 5 Comparaisons of acoustic power of machines _ Field 5

Field 6
Land-surveying : rugged fields, some vegetation.
Type of windturbines : 1300 kW, hub heigh : 60 meters

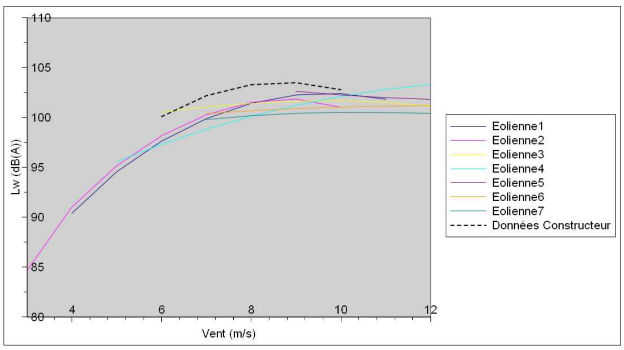

Figure 6 Comparaisons of acoustic power of machines _ Field 6

Analysis

By analysing these figures, we can make the following conclusions :

- We can see important dispersion on acoustic power of same type of machines on the same field. The measured dispersion can reach 10 dB(A) between the most noisy and the less one.
- Generally, data on manufacturer's databook are up or equal to the measured ones. However, we can see some exceedances. They can reach 5 dB(A) for a particular range of wind speed (generally for low speed).

These conclusions can have important consequences on the acoustic impact of windturbines fields. In fact, results of forward-looking acoustic studies depend on certified acoustic power values. All windturbines have the same acoustic power value. In case of exceed of manufacturers'

guaranteed values, the results and conclusions can be false instead of the study was well made.
That's why it's important to have a better knowledge of phenomenon acting on the dispersion of noïse between same type of windturbines on a field, in order to predict situations like the one described before.

Origins of windturbine's noise

Different studies have shown that we can divided the noïse emmited by a windturbine in two classes :

- Mechanical noise [5]
- Aerodynamic noise [6]

Mechanical noise sources

The mechanical noise is made by all components on the nacelle. The main component responsible for this noïse are the multiplicator, shafts, the generator and auxiliary fittings (hydraulic systems, cooling system,...). the noïse emmited as a wide frequency range, but it contains harmonics linked to rotating parts.

Sources of aerodynamic noise

The noise emmited is directly linked to the speed flow.
All the other parameters don't change, the sound pressure will increase by the fifth potenty of the blade. That's why the rotation speed of modern widturbines, with big rotor, is very slow.
All of these aerodynamic noises are generated by turbulences. They have different origins :

- Dirt and defaults on the blade profile (holes, cracks,...)
- Turbulences linked to the air flow on the intrados and extrados part of the blade, meeting at the end of the blade and creating turbulences on the trailing edge.
- Swirl at the end of the blade generated by excessive pressure/vaccum on this area.

The different areodynamic noises emmit at different frequency ranges. Finally, the total aerodynamic noïse looks like a white noïse. The figure below shows the spectral contributions of the different sources of areodynamic noïse and the global spectrum [5].

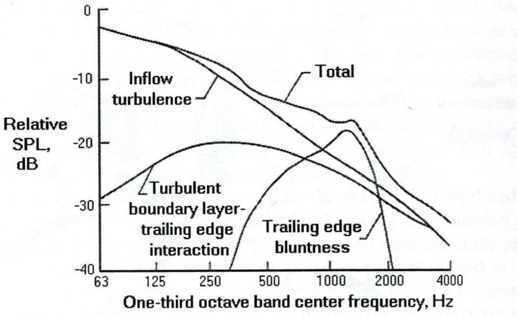

Figure 7 Relative contributions of aeroacoustic noise sources to the total noise spectrum (from Grosweld, 1985)

On a blade, the sources of aerodynamic noïse are localised on the trailing edge and at the boundary. On this part, flow speeds are the highest ones.

These sources of mechanical and aerodynamical noïses are propagating by the air,but by solids too. The mechanical vibrations and aerodynamic turbulences make all the winturbine structure vibrating : blades, nacelle and mast.

Possible explanations on the dispersion of sound emission of windturbines

Wind gradients and machine size

The wind speed is nul on the floor, and increase with the heigh. This phenomena is called wind shearing.
It can be estimated by a logarithmic extrapolation or a potency law. The more flat the floor will be, the more fast this increase will occur.
The wind shape and it's profile are caracterised by two parameters :

- The surface roughness
- The vertical gradient coefficient of wind speed (alpha) [7]

We can obtain these parameters by a wind measurement at two different heights.
Now, we can reach the wind speed V_0 at the height by knowing the value of the vertical gradient of the wind speed (α) and the wind speed V at the height H by this formula :
La détermination de ces deux paramètre est possible par une mesure du vent à deux hauteurs.

$$(V/V_0) = (H/H_0)^{\alpha} \quad (1)$$

with :
α : coefficient of the vertical gradient of the wind speed
V : wind speed in m/s at the heigh H (m)
V_0 : wind speed in m/s at the heigh H_0 (m)

Today, the big windturbines have mast height and rotor diameter up to 80m. So the boundary of the low blade goes at 40m to the floor (in low position) to 120m in high position.
For an open field with a few vegetation, we assume that the coefficient of the vertical gradient of the wind speed (alpha) is equal to 0.2. This creates a difference of 2m/s between the wind speed at 40m and the one at 120m. Therefore the disk that describes the rotating blades is not submit to the

same speeds, but the reference wind speed for measurement is measured at only one height.
Moreover, the vertical wind profile on one point depends on the physical parameters of the field around this point (height of near obstacles, relief). In consequence the vertical profile will be different for different places on the field.

Wind index

On laminar flow, the horizontal component of the wind is parallel to the floor. Windturbines rotors are optimally orientated in comparison to the wind incidence. This concordance doesn't take into account relief variations induct by a local modificaiton of this incidence.
This difference between the real wind incidence angle in comparison to the optimum concordance of the rotor creates a modification of aerodynamic conditions and windturbine production. Thinking about the complexity of each field, we can't assume that wind incidences on each machine are the same.

Wind turbulences

Turbulences are difficult to predict because they are variable on space and time. They depend on different parameters.

- Thermic conditions
- Relief
- Obstacles

As we said before, turbulences are a source of the aerodynamic noïse of the blades.

Blades defaults

Like all the components of a windturbine, pales are made by mass-produce. So that's quite normal that they don't have exactly the same characteristics (defaults, holes,...) are random defaults, that increase the aerodynamic conditions.

Diversity and assembling components

All components needed for the fonctioning and the production of electricity are results of mass-produce too. They have their own characteristics linked to the different events on the production line.Their functioning interaction can't be the same on different assembly. Moreover, these mechanical noïses are likely to have some variations, depending on forces on meachanical parts, gears,.., and on the transmitted power and the spatial and temporal regularity of forces acting on blades.

Conclusion

We have seen a dispersion (sometimes important) of sound emission of same type of machines working on the same conditions on a windturbine field. This dispersion can be really bad for previsionnal sound impact studies, because on the existing models, all machines are supposed to emmit the same noïse level. The noïse created by a windturbine comes, in one hand, from a aerodynamic part, and , in another hand, from a mechanical part.

We have begun to think about the penomenon responsible for this dispersion : wind profile variation, turbulences conditions, complexity of gradients, components diversity. Each of these phenomenon was interacting with others, so the next researches we'll focus on will be the designation of the influence of each parameter on the variation of the global windturbine level.

References

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