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Continuous noise monitoring of wind turbines

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Abstract

LBP|SIGHT are monitoring wind turbine noise since November 2009 at different sites in the Netherlands. The measured turbines are all large 2 – 3 MW Wind turbines positioned in the centre of the Netherlands, as well as near the seashore. At each site a measuring system is installed consisting of three microphones around a turbine and two anemometers to measure the relationship between the wind velocity and sound level of this turbine. Also the turbine data from the scada system is used in the monitoring. All data is collected continuously and automatically and stored in a database accessible through the internet. The aim of the measurements is to get insight in the L_{den} of a representative year. The sound regulation for wind turbines is recently changed in the Netherlands from a nightly L_{eq} to a yearly L_{den}. The data is processed automatically so that during the measurements results can be obtained of the relation between the sound power level and the wind velocity at 10 metres, wind velocity at hub height, wind direction, and other factors. With these results the effects of directivity and wind shear can be acquired. The results can be sorted in different ways, for example by wind direction, by day- or nighttime or by season. The microphones are positioned close by according to the IEC 64110. This article will discuss the measurement system, the sites, the calculation and the so far obtained results.

Introduction

In 2008 the Dutch government was planning to change the noise regulation for wind turbines. The reason for this intention was the discussion between developers and opponents about the effect of wind shear on the noise immission. The existing regulation is a curve in which the permitted sound level L_{eq} rises with the wind velocity at 10 metres height. During a night with a certain amount of wind shear the wind velocity at 10 metres height might be considerably lower than the wind velocity at hub height. This would cause a discrepancy between the noise emission and the sound limit. The effect of this discrepancy is cause for much discussion during the procedures for new wind parks and has let to delay and cancellation of wind parks. The yearly average L_{den} is proprosed as the quantity for the new regulation. This L_{den} is based on the wind statistics at hub height.

This proposed change to a yearly average led to monitoring programs set up by LBP|SIGHT. In a joint assignment of different wind park developers and energy companies LBP|SIGHT are now monitoring the noise of different wind turbines at several sites in the Netherlands. The aim of these measurements is to study the amount and frequency of wind shear on different locations in the Netherlands, to study the effect of this wind shear on the noise emission and to measure the yearly L_{den} value.

Measurements and processing

Measurements of wind turbine noise are mostly done according to the IEC61400-11 as this method gives the most consistent results free from wind-induced noise and other disturbances. For a long term monitoring this IEC method was used as a guideline but some deviations had to be made.

The first problem is the positioning of the microphone. The IEC requires a flat and hard surface but this would cause problems with rain and water on the surface. Instead, the microphone is placed on a slanted surface, which is additionally sheltered from above. Figure 1 shows the mounting. This set-up is also covered with a secondary wind screen. The function of the top shelter is not only to reduce the amount of rain on the microphone but also to increase the noise of rainfall. The filtering out of the measurement samples during rainfall is easier with this increased noise level.

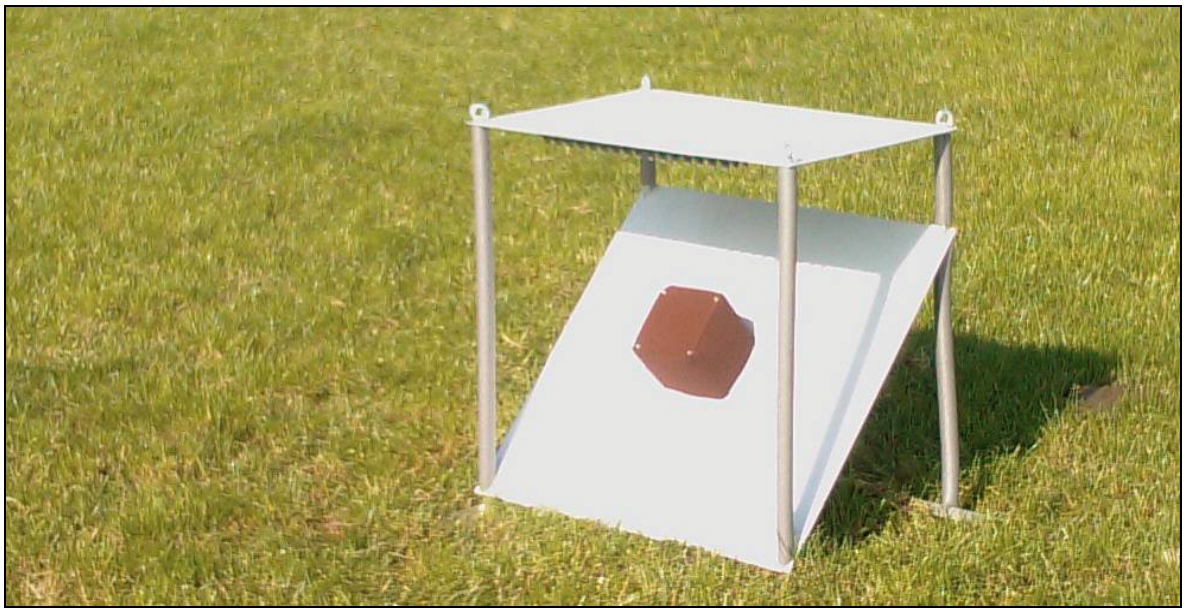

Figure 1 Microphone orientated to the rotor centre

A second deviation is the distance from the noise measuring position to the wind turbine. This distance is decreased from hub height and half the rotor diameter to only the hub height. This shorter distance gives a higher signal which increases the signal to noise ratio for the automatic processing of the data.

These deviations of the IEC standard do not affect the measurement results. The set-up is calibrated by performing a manned measurement according to the IEC and comparing the results with the monitoring set-up. In figure 2 this comparison is shown. The difference is 0.2 dB. In table 1 the spectral differences are given. In the low frequencies the difference is probably caused by the not completely cancelled out ground effect due to the slanted plate and in the high frequencies by attenuation of the rain shelter.

Table 1
The spectral difference of the IEC measurement and the monitoring set-up

Level monitoring set-up minus IEC measurement:		Octave [Hz]							
		63	125	250	500	1k	2k	4k	8k
Difference:	-0.2 dB	0.5	0.5	-0.3	-0.4	-0.2	0.1	-1.9	-4.3 dB

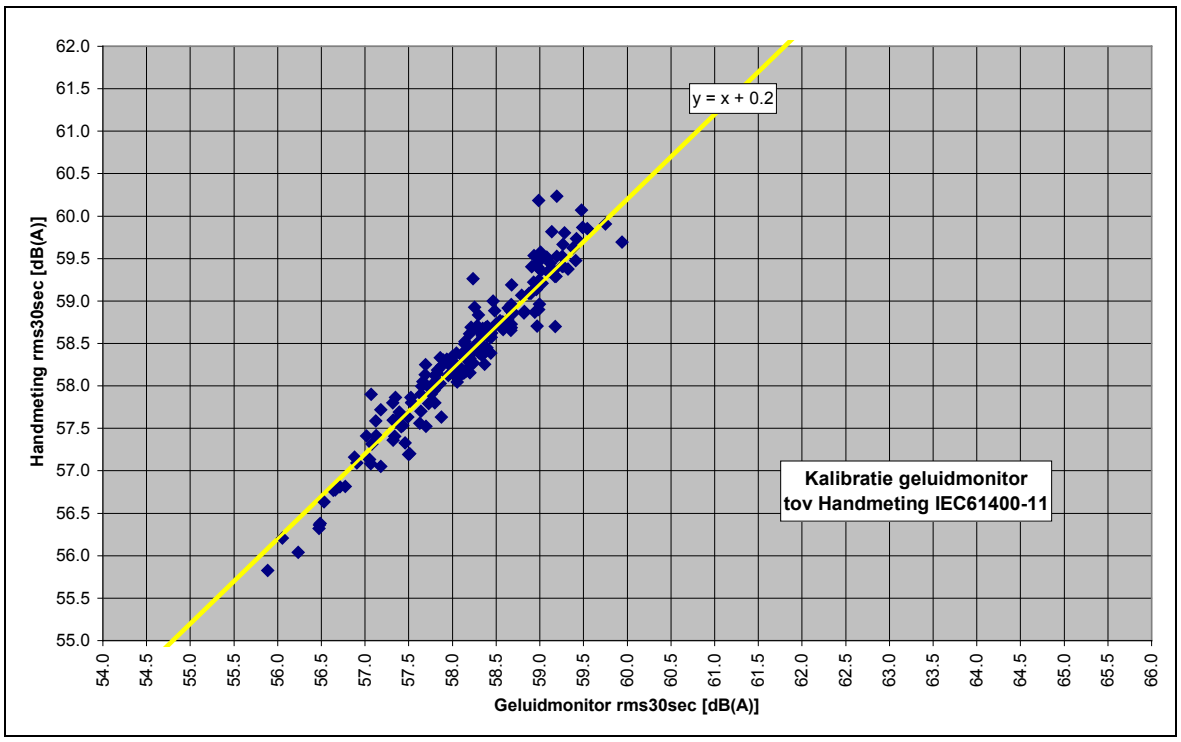

Figure 2 Difference between IEC measurements and monitoring set-up

Figure 3 Positioning of the three microphones and one of the two anemometers around the wind turbine

At each wind turbine three microphones are positioned around the turbine. Two cup anemometers are positioned on a mast at 10 metres height. In figure 3 the total set-up at one of the turbines is pictured. In the turbine a central processing unit (cpu) is placed which processes the five signals (three sound, two wind) and transmit them to a central web server (www.geluidbeheer.nl). On the server the data is stored in a database after the following processing. Each second a root mean square noise level is stored of each octave. Each second the wind velocities are recorded. Hourly and ten minutes averages of both noise and wind are calculated. Data from the wind turbine is also stored in the same database. This data is the ten minute average of the wind velocity at hub height, the wind direction on hub height (positioning of the nacelle), the electrical output and the revolutions per minute (rpm).

To filter out disturbances and non valid data, several checks are made. For example, the rpm of the rotor has to be higher than zero to check if the turbine is in operation. Furthermore, the wind velocity on hub height has to be at least 1 m/s to check for inconstancies, and also the results at very very high (> 25 m/s) wind speeds on the 10 metres masts are not taken into account (the wind turbine will then be shut off).

Results

With all the data on the server different results can be examined. Some subsets of the results will be discussed in this article.

In figure 4 the measured sound level is plotted against the measured wind velocity. This relation can be used for the calculation of the sound power level. This relation is obtained from measurements during one month.

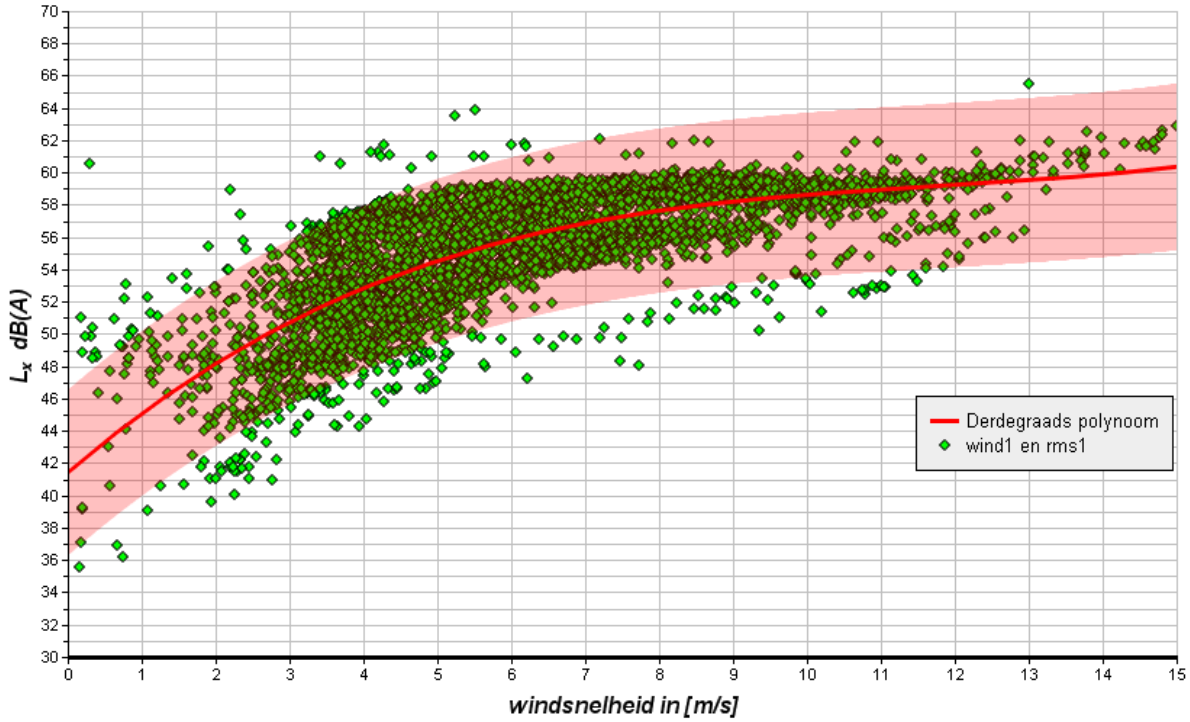

Figure 4 Measured sound pressure level against V_{10} during nighttime for one month

The wind shear (the wind velocity at hub height divided by wind velocity at 10 metres height) is shown in figure 5 for daytime and figure 6 for nighttime. Although the factor V_{hh}/V_{10} hovers around the line depicting a neutral atmosphere (in this example 1.2 for a hub height of 80 metres). It is clear that during some nights the factor is much higher due to a stable atmosphere. On these nights the measured sound level will be higher than expected from the V_{10} during those nights.

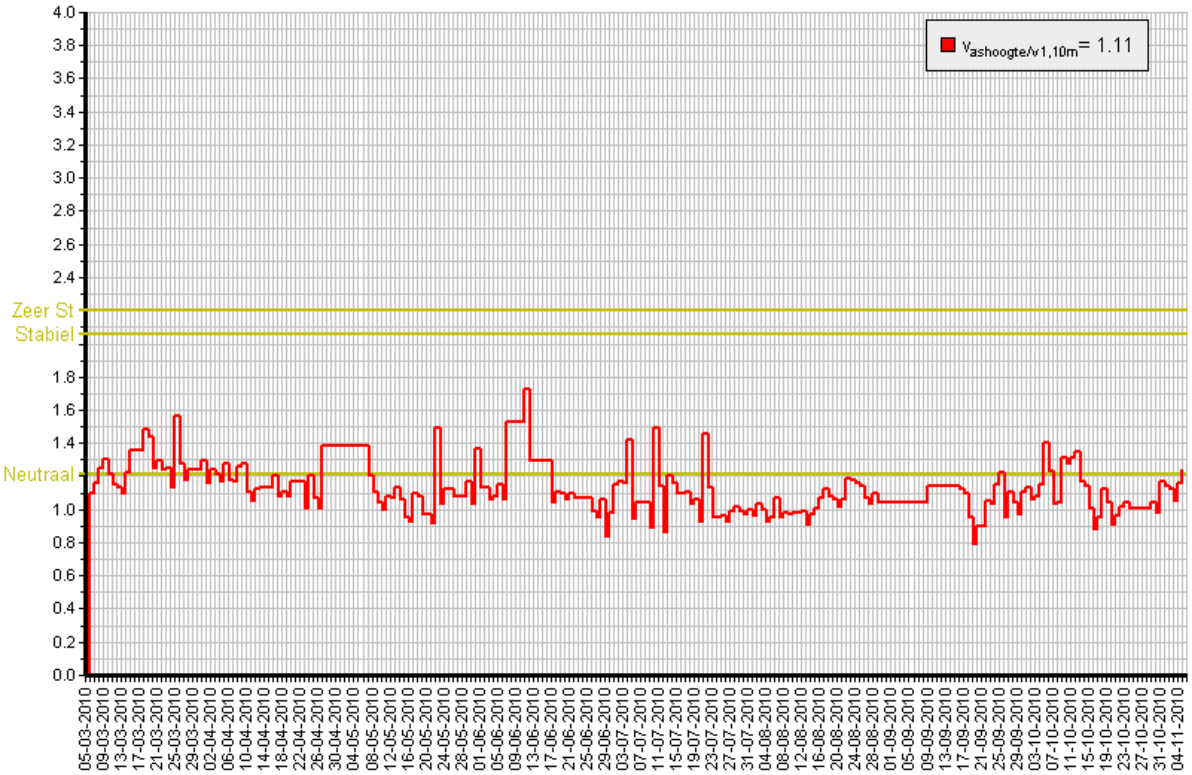

Figure 5 Average V_{hub}/V_{10} during daytime for several months

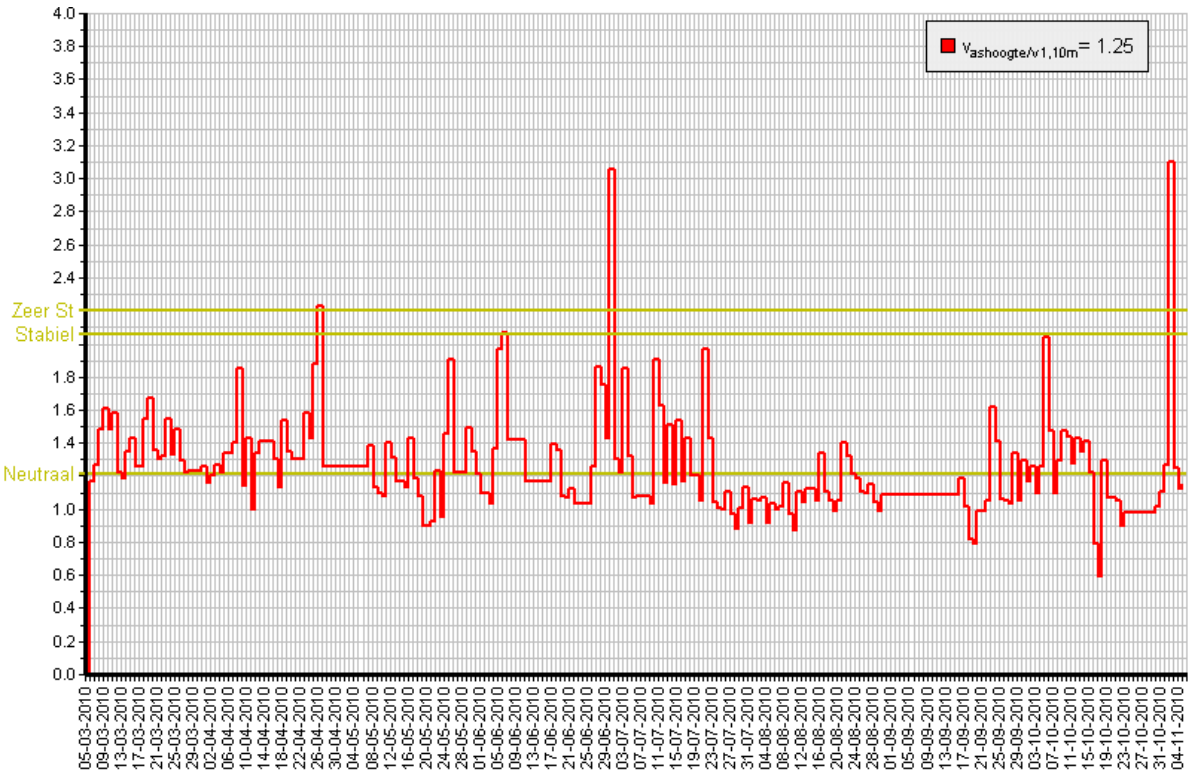

Figure 6 Average V_{hub}/V_{10} during nighttime for several months

The effect of this wind shear for the sound level can be calculated according to the old Dutch noise regulation. This regulation is called the WNC. The sound levels are corrected for wind velocity at 10 metres height according to table 2. The resulting level should be 40 dB(A) or lower at dwellings during the night (an eight hour equivalent). According to Dutch law this 40 dB(A) noise limit should be met almost every night of the year. A few exceptions a year are tolerable, usually 12 a year. This means that when measuring for one year, the 13th highest noise level of the year is representative. In figure 7 the levels in nighttime according to the WNC regulation are given. The 13th highest level (with reference to one year) is 55.8 dB(A) (this level is at the measuring position, not at a dwelling). This level in this example is 0.9 dB higher then calculated if wind shear due to non-neutral atmospheric conditions was not taken into account. So for this turbine at this position the effect of stable atmospheric conditions is 0.9 dB during three months of measuring. The effect of wind shear due to higher than standard roughness length is considered to be almost zero for this site.

Table 2
Correction of sound level according to the WNC

V_{10} [m/s]	3	4	5	6	7	8	9	10	11	12
Correction [dB]	-1	-1	-2	-2	-3	-4	-6	-7	-8	-10

The level obtained according to the old Dutch regulation can be compared to the new regulation. The new regulation states a maximum yearly average L_{den} of 47 dB. The L_{den} is calculated by adding 0, 5 and 10 dB to respectively L_{day}, $L_{evening}$ and L_{night} and subsequently averaging the levels time-weighted. In a formula:

$$L_{den} = 10\lg\frac{1}{24}\left(12*10^{\frac{L_{day}}{10}} + 4*10^{\frac{L_{evening}+5}{10}} + 8*10^{\frac{L_{night}+10}{10}}\right)$$

The L_{day}, $L_{evening}$ and L_{night} are the equivalent levels during the periods 7.00 to 19.00, 19.00 to 23.00 and 23.00 to 7.00 hours. Figure 8 shows the levels at each day during a year. If this period of three months of measuring is representatieve for a whole year than a L_{den} of 61.1 dB is obtained. So for this wind turbine, with these surroundings, a L_{den} of 61.1 dB is measured together with a WNC corrected noise level of 55.8 dB(A). The difference (L_{den} – WNC) is 5.3 dB. This difference is less than the difference between the old en new regulation: The limit for the L_{den} is 47 dB and for the WNC 40 dB(A) and thus the difference between the nose limits is 7 dB. If this wind turbine meets the old noise limit exactly than the L_{den} of this turbine will be 45.3 dB and thus meets the maximum allowed level of 47 dB.

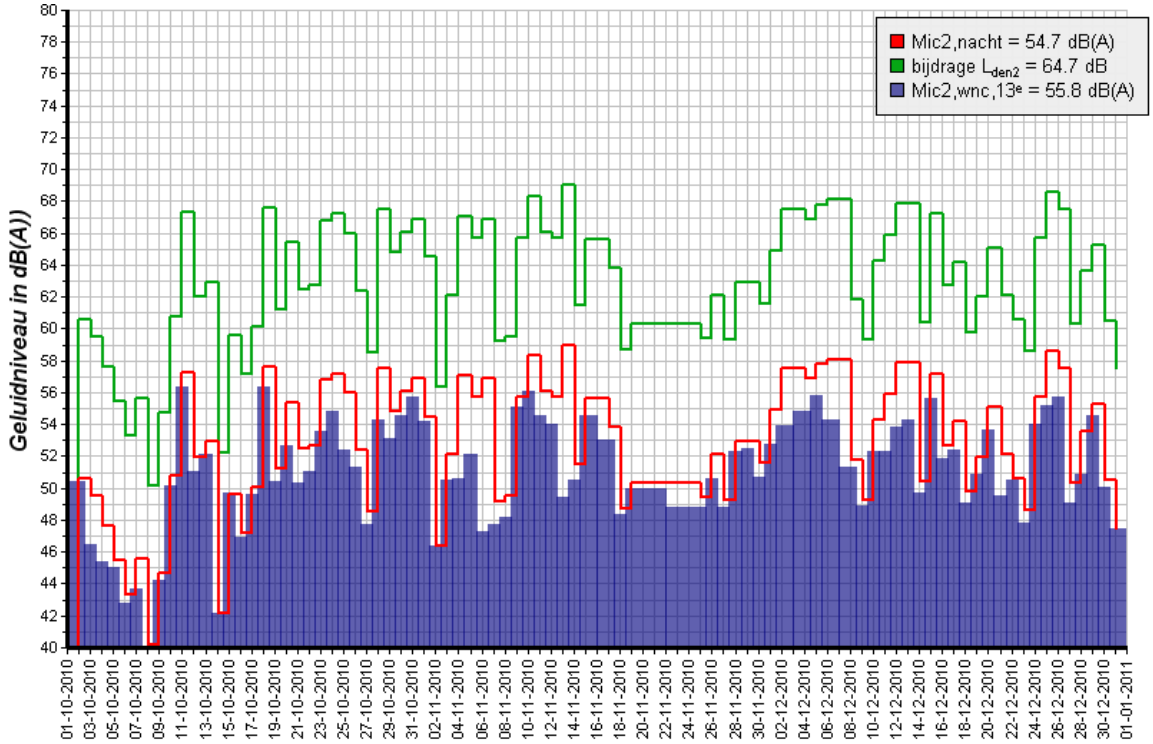

Figure 7 Average nighttime sound levels (red: measured, green: +10 dB correction for L_{den} during night, blue: correction for V_{10} according to Dutch WNC)

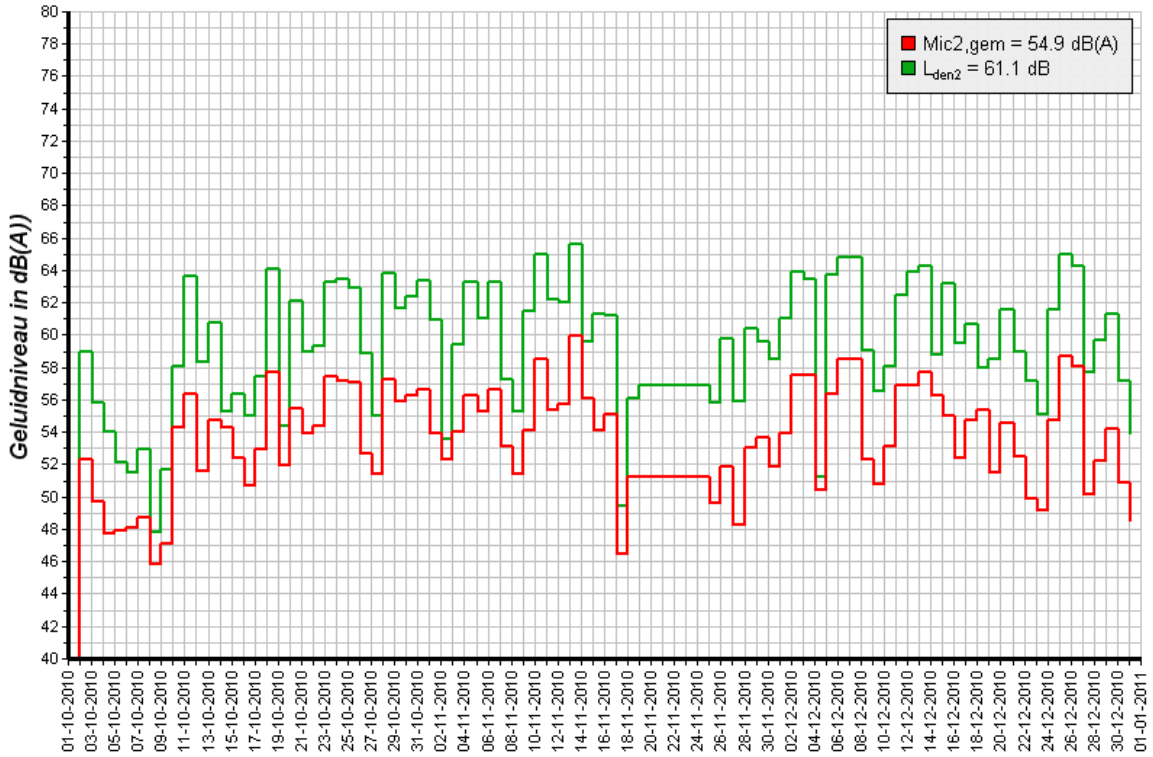

Figure 8 Average 24hours sound levels (red: measured, green: corrected for L_{den}, blue: correction for V_{10} according to Dutch WNC)

In figure 9 an example of the measurements results of directivity is shown. This figure is valid for a wind velocity of 6 m/s at hub height. The graph is obtained by plotting the measurement results at one of the microphones against the orientation of the nacelle. In this example the average level downwind (in the direction of the microphone) is 51 dB. The lowest averages are found halfway and are about 46 dB. The effect of directivity resulting from this graph is thus 5 dB. By combining all the results from the three microphones the directivity for all directions can be calculated for all the wind velocities.

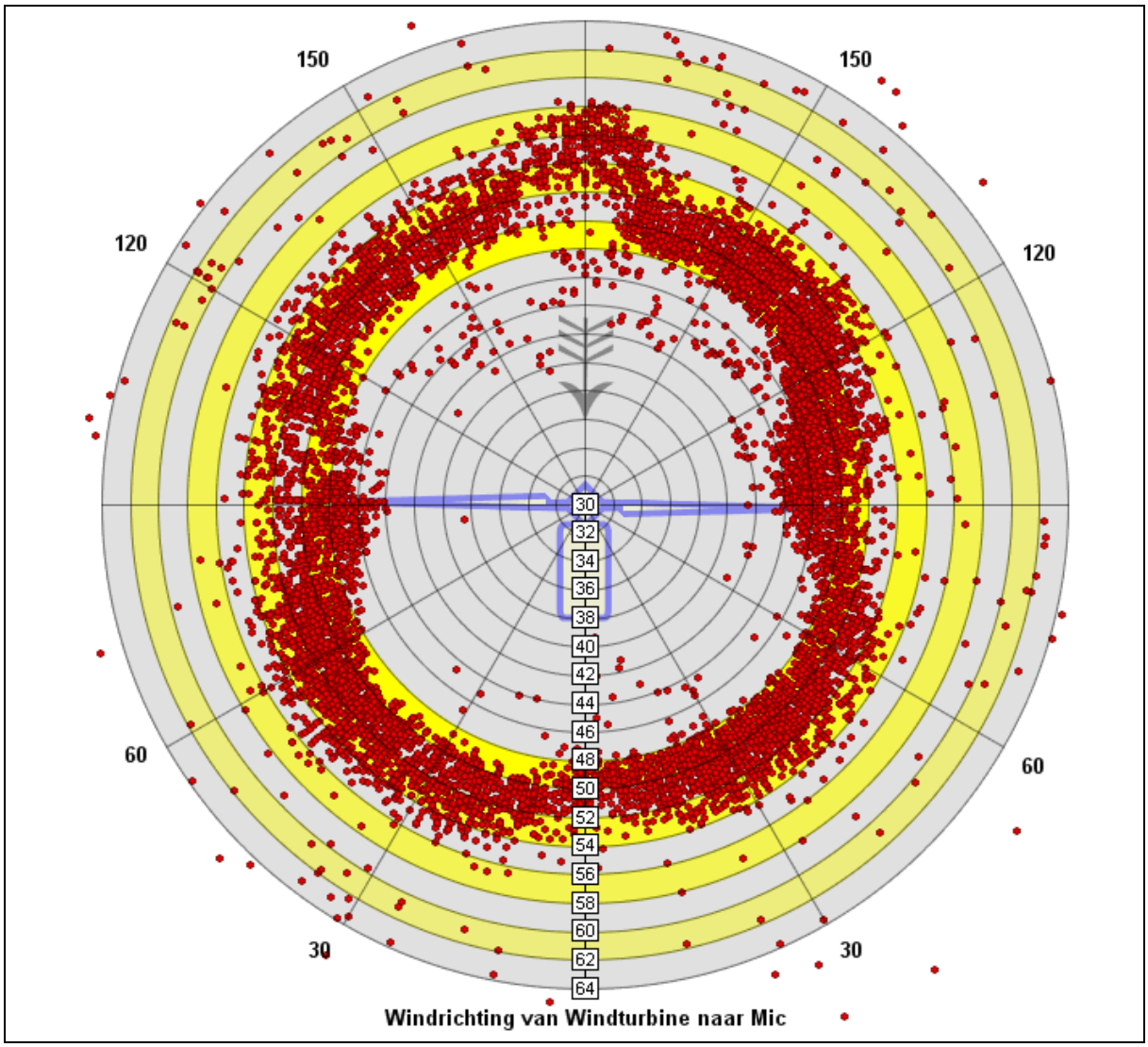

Figure 9 Directivity at V_{hh}=6 m/s when the rotor is facing one of the microphones (some noise disturbance exists in this example at a wind direction exactly from wind turbine to the microphone)

Conclusions

Continuous noise monitoring of a wind turbine is feasible provided the distance between turbine and microphone is not too large. In this research the distance between tower base and microphone was the same as the hub height. By using three microphones around the turbine the resulting data can be processed for different wind directions (wind from sea or wind from land). Also the directivity of the rotor can be examined.

The results show that wind shear to stable atmospheric conditions can be a relevant factor although the effect on the noise immission is small.

The L_{den} of a wind turbine can be calculated by monitoring the sound level. The effect of the change in Dutch law from a WNC corrected noise limit of 40 dB to a yearly average L_{den} of 47 dB is depending on the turbine type and the positioning of the turbine. The measurements results of a period of more than a year show a difference between site near the sea and inland sites.

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