5th International Conference
on
Wind Turbine Noise
Denver 28 – 30 August 2013

Low Frequency Noise from Wind Turbines: Do the Danish Regulations Have Any Impact?

Bo Søndergaard Grontmij A/S Dusager 12 8200 Aarhus Denmark
E-mail: bo.sondergaard@grontmij.dk

Summary For several years the concern that low frequency noise from wind turbines could cause serious annoyance for the neighbours has been a dominant factor in public debate in Denmark. From the beginning of 2012 the Danish regulations were revised and a criteria for the amount of in-door low frequency noise were introduced. Results from new and old measurements of noise from mainly Danish produced wind turbines are analyzed and compared with the Danish regulations for noise and low frequency noise. In most cases low frequency noise is not an issue. All measurements are for existing wind turbine projects and commercially available wind turbines excluding prototypes.

1. Introduction

Around 2004 – 2005 low frequency noise from wind turbines became a major concern in the public in Denmark. There were a worry that larger wind turbines would emit substantially more low frequency noise than the wind turbines people knew already. As this had consequences for the development of on-shore wind energy the Danish energy authorities initiated an investigation into the topic. The results were reported in **Error! Reference source not found.** and [1] by DELTA and an alternative interpretation were reported by the acoustics department at the University of Aalborg [3] and [4]. In December 2011 the Danish regulations on wind turbine noise were revised and noise criteria were introduced for the in-door low frequency noise. Details on the regulations and the background can be seen in [5]. Sørensen presented some of the consequences for the planning process in [6].

2. Investigations

The question then is; do the new regulations have any impact on low frequency noise from wind turbines and how can it be checked. As the neighbours are the main objective for the new regulations a set of wind farm projects, where Grontmij have been involved in the post construction documentation of noise are reviewed. Another interesting parameter which have been used as an indicator is the sound power level of the wind turbines. An analysis of Grontmij's database on wind turbines have been made to see if there is a development.

2.1 Noise from wind farms. As a consultancy Grontmij is often involved in post construction documentation of noise from wind farms. In Denmark this includes determination of the sound power level of individual wind turbines and prediction of the noise in the surroundings. In Figure 1 the noise contours around a wind farm is shown. The blue line is 42 dB(A), the red line is 44 dB(A) and the pink line is 20 dB(A) indoor low frequency noise, all at 8 m/s. Typically for the projects Grontmij have seen, the pink curve for low frequency noise is enclosed by the other curves indicating that low frequency noise is not the decisive parameter.

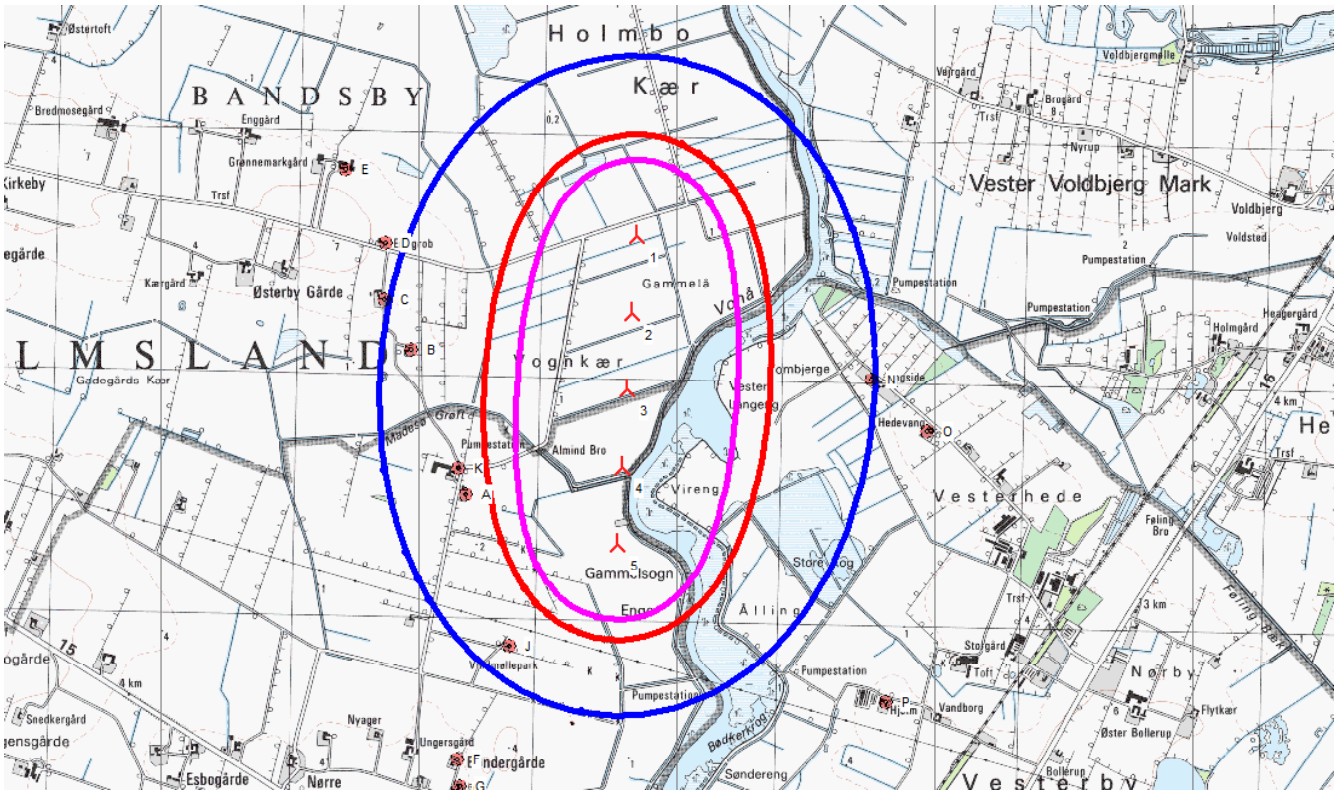

Figure 1. Typical noise contours for a Danish wind farm at 8 m/s. The blue line is 42 dB(A), the red line is 44 dB(A) and the pink line is 20 dB(A) indoor low frequency noise.

In Table 1 results from the noise prediction for 6 wind farms are shown according to the Danish regulations. The first 3 projects are planned and erected before the regulations on low frequency noise were introduced. The last 3 were planned with the new regulations as a design criteria. Project no. 3 is actually a much older project with new measurements made in 2013 allowing for a comparison with the new criteria. The numbers in the parenthesis show the margin to the noise criteria. For the normal noise the margin is typically up to 2 dB, while it is in the range of 3 to 7 dB for low frequency noise. This again indicates that it is the “normal” noise which is the decisive parameter and not the low frequency noise.

From these data it is difficult to conclude on the difference between older and newer projects. It looks more like low frequency noise from new and old projects are of the same order at the neighbours.

Project	Wind Turbines	Neighbour with highest noise level				
		Distance [m]	L_{pA} (6 m/s) [dB]	$L_{pA,LF}$ (6 m/s) [dB]	L_{pA} (8 m/s) [dB]	$L_{pA,LF}$ (8 m/s) [dB]
1	6 V90-3MW	656	39,9 (2,1)	14,8 (5,2)	42,6 (1,4)	17,3 (2,7)
2	6 SWT 2,3-93	700	41,1 (0,9)	14,4 (5,6)	43,3 (0,7)	16,8 (3,2)
3	3 600 kW WTG	304	41,2 (0,8)	12,7 (7,3)	42,7 (1,3)	14,4 (5,6)
4	5 SWT 3.0-101	587	42,6 (-0,6)	13,7 (6,3)	43,5 (0,5)	16,1 (3,9)
5	3 V112-3MW	810	36,3 (0,7)	11,0 (9,0)	37,9 (1,1)	12,7 (7,3)
6	3 SWT 3.0-101	574	41,4 (0,6)	12,5 (7,5)	42,1 (1,9)	14,9 (5,1)
Noise criteria			42/37	20	44/39	20

Table 1. Main results from typical wind farm projects in Denmark. The numbers in parenthesis show the margin to the noise criteria. For project 6 at 6 m/s the noise is above the noise criteria. It is allowed for owners and part owners to exceed the noise criteria at their own residence. Note that the neighbour with the highest noise level is not always the neighbour with the shortest distance.

2.2 Noise emission from wind turbines. Much of the discussion so far has been based on sound power levels of the wind turbines and whether the wind turbines generate more low frequency noise when the size increases. For this review an analysis based on 213 measurement reports are made. All the original data from the project in **Error! Reference source not found.** are included, except for the prototype wind turbines. Data are supplemented with measurement reports from the archives at Grontmij, where 1/3-octave band data were available, and new measurement reports. The reports represent wind turbines ranging from a few kW to the newest version of MW turbines.

The analysis is based on the same principles as in **Error! Reference source not found.**, [1], [3] and [4] but on a much better statistical basis with 213 measurement reports. As the new data also includes older types of stall regulated wind turbines with a nominal power between 2000 kW and 2800 kW sorting of data is a little different. The data are sorted into 4 classes: ≤ 200 kW,]200 kW – 1000 kW],]1000 – 2000 kW], >2000 kW, >2000 kW old types and >2000 kW new types. This makes it possible to evaluate new large wind turbines compared to wind turbines designed and erected before the investigation in **Error! Reference source not found.** and [1] was published. For comparison with previous investigations the class]200 – 2000] is included The spectra are normalised to L_{WA} of the individual wind turbine before averaging. A comparison of the averaged spectra for each class can be seen in Figure 2 and the number of spectra in each class can be seen in Table 2.

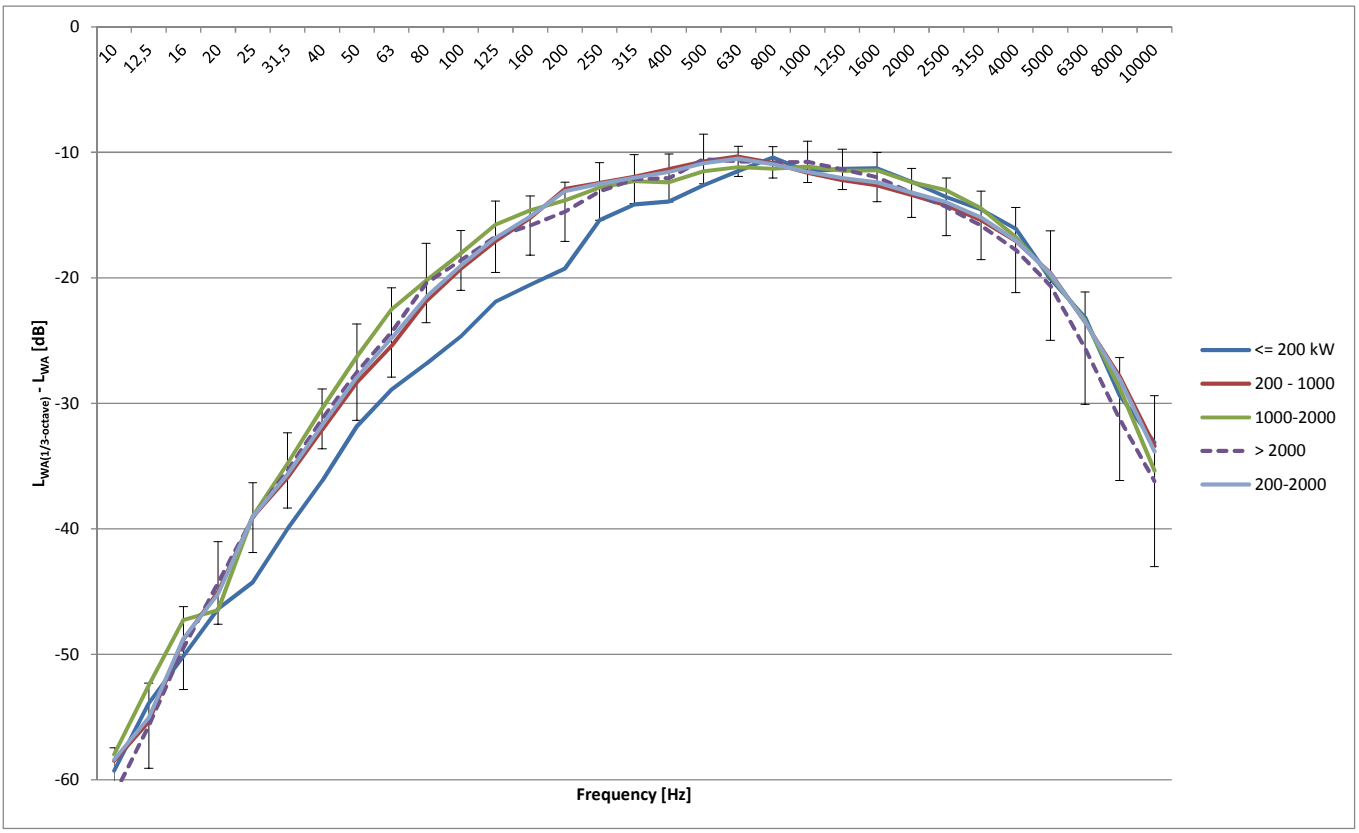

Figure 2. Comparison of normalized spectre sorted after nominal power into different classes. Error bars show ± 1 standard deviation on the mean in every 1/3-octaveband for wind turbines above 2000 kW.

Class	Number of spectra	Number of spectra at 10 Hz
≤ 200 kW	16	5
]200 kW – 1000 kW]	108	5
]1000 kW – 2000 kW]	27	1
> 2000 kW	62	27
]200 kW – 2000 kW]	135	6
> 2000 kW new	34	23
> 2000 kW old	28	4

Table 2 Number of spectra in each class. As not all measurements are covering the entire frequency range the count of spectra with 10 Hz 1/3-octave band is shown as well.

All spectra are measured down to at least 50 Hz and for the new large turbines down to at least 16 Hz.

The spectra representing the different classes does not deviate much in the low frequency region from 10 Hz to 160 Hz, except for the class of wind turbines below 200 kW. These turbines are relatively rare these days and due to the early design are dominated by machinery noise and tonal noise. Small wind turbines are represented by the class from 200 – 2000 kW which is consistent with previous analyses. In Figure 3 a comparison of small and large wind turbines are shown. The differences in the low frequency range are small, which can be seen in more detail in Figure 4, where the spectrum for small wind turbines are subtracted from the spectrum for large wind turbines. It is clear that the class of turbines above 2000 kW deviates very little from the small wind turbine spectrum and positive deviations are less than 1 dB.

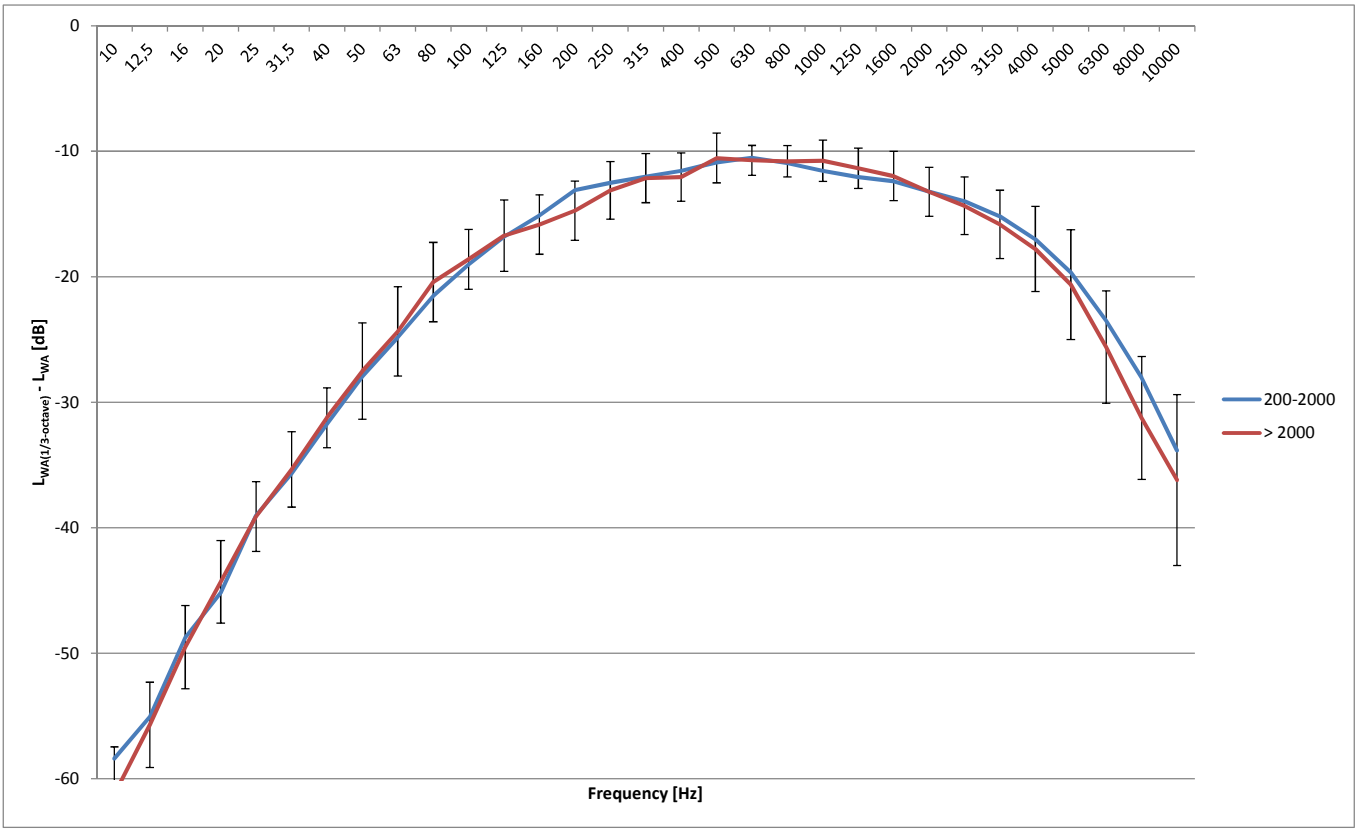

Figure 3, Comparison of small and large wind turbines.

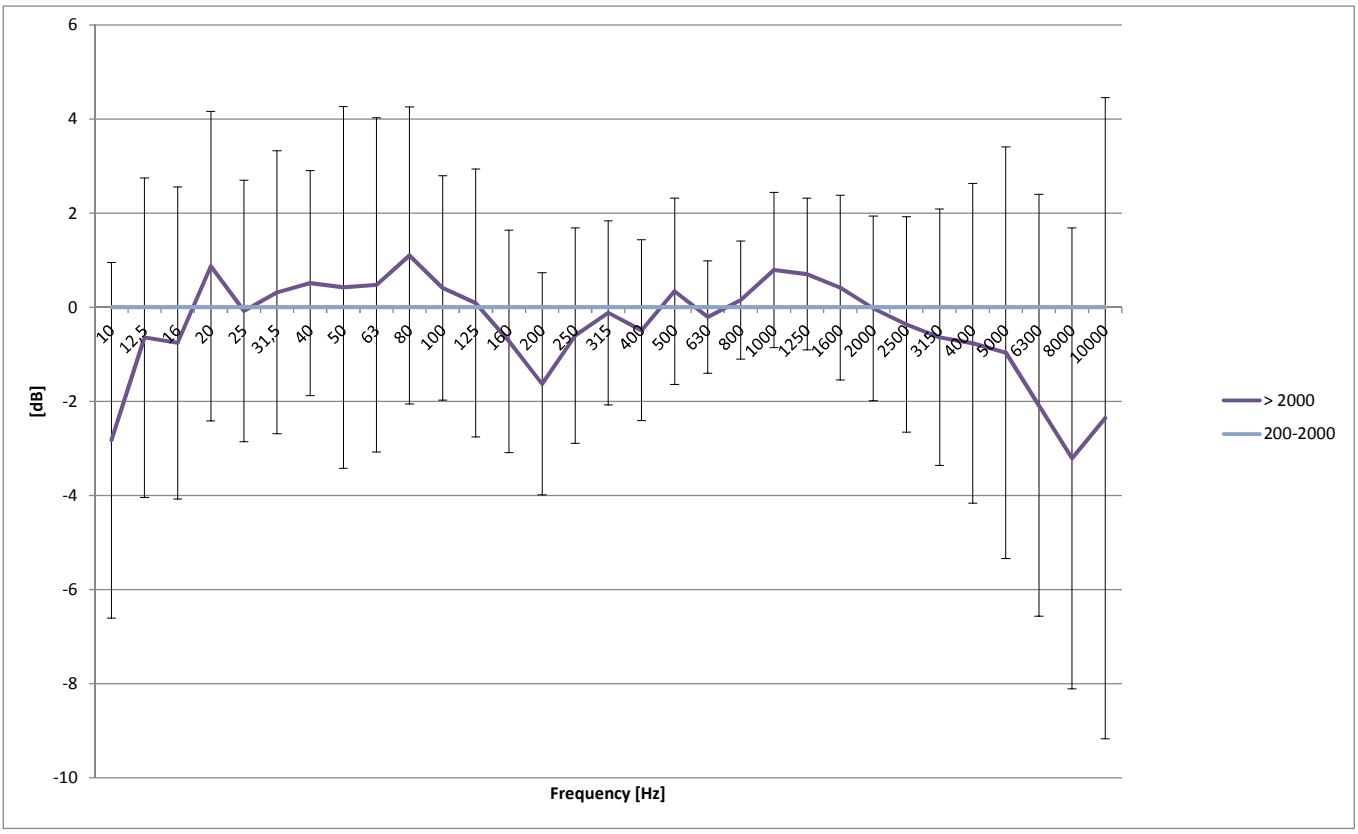

Figure 4 Spectrum for the class of wind turbines relative to the spectrum for the 200 – 2000 kW class. the spectrum for the 200 – 2000 kW class is subtracted from the spectrum for the class > 2000 kW. A negative value means that the level at that frequency is lower than the corresponding value for the reference spectrum. Error bars show ± 1 standard deviation on the mean in every 1/3-octaveband for turbines above 2000 kW.

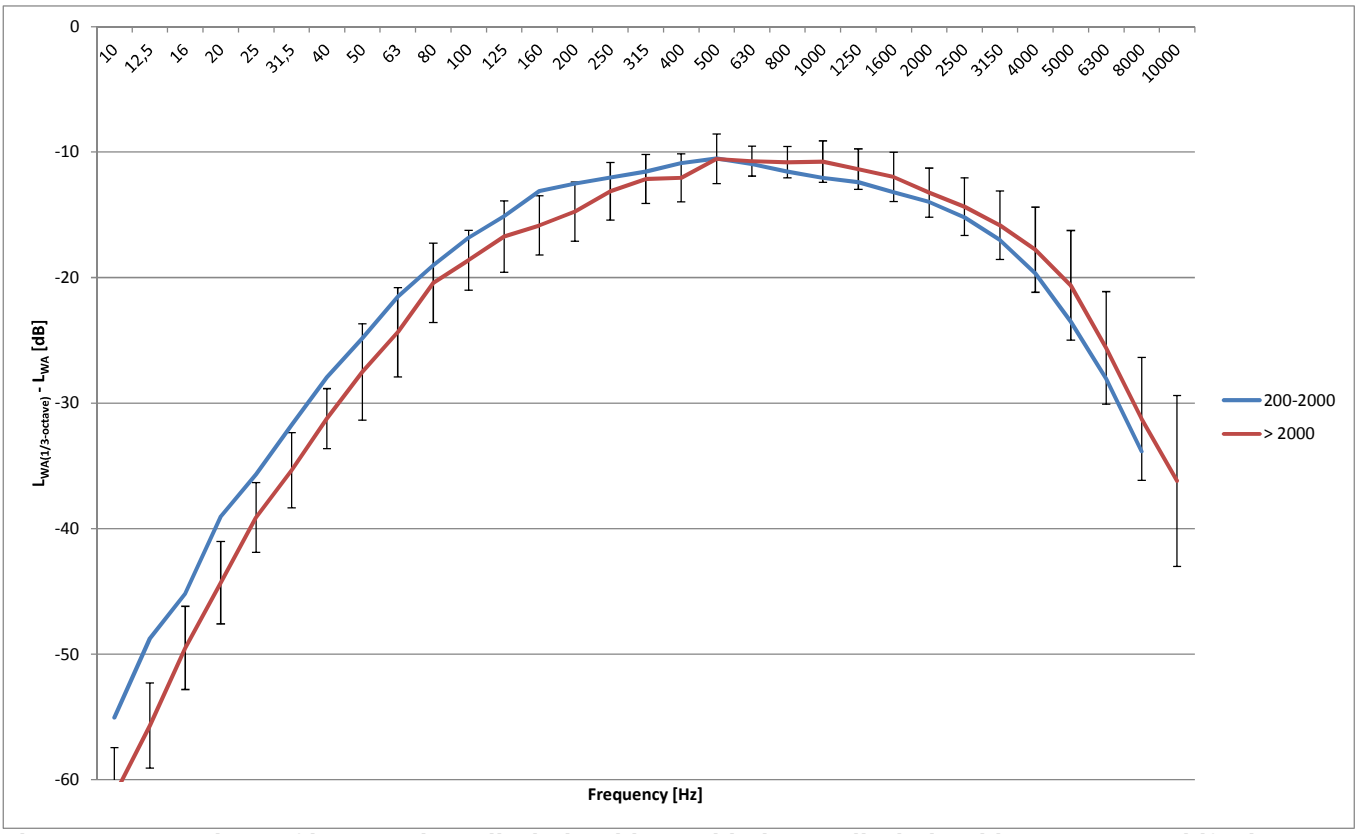

Figure 5 Comparison of large and small wind turbines with the small wind turbine spectrum shifted one 1/3-octave down as suggested by Møller in [3] and [4]. The comparison shows that the development of low frequency noise with size is not as strong as assumed by Møller.

It has been suggested by Møller in [3] and [4] that the development in low frequency noise with size corresponds to a shift by one 1/3-octave in the spectrum. In Figure 5 a comparison is made where the spectrum for small wind turbines are shifted one 1/3-octave down. It is obvious that the normal presentation in Figure 3 gives a better match between spectra and the assumption can be rejected.

A comparison between new and old wind turbines are made in Figure 6. The definition is a little diffuse, but measurement reports from before 2010 are considered to be old and after 2010 as new. There is a clear difference in the frequency range from 100 Hz to 500 Hz where the relative amount of noise is lower for the new wind turbines than for the old wind turbines. This suggests that there is a development towards less low frequency noise, possibly because tonality in this frequency range is an area of focus for the developers.

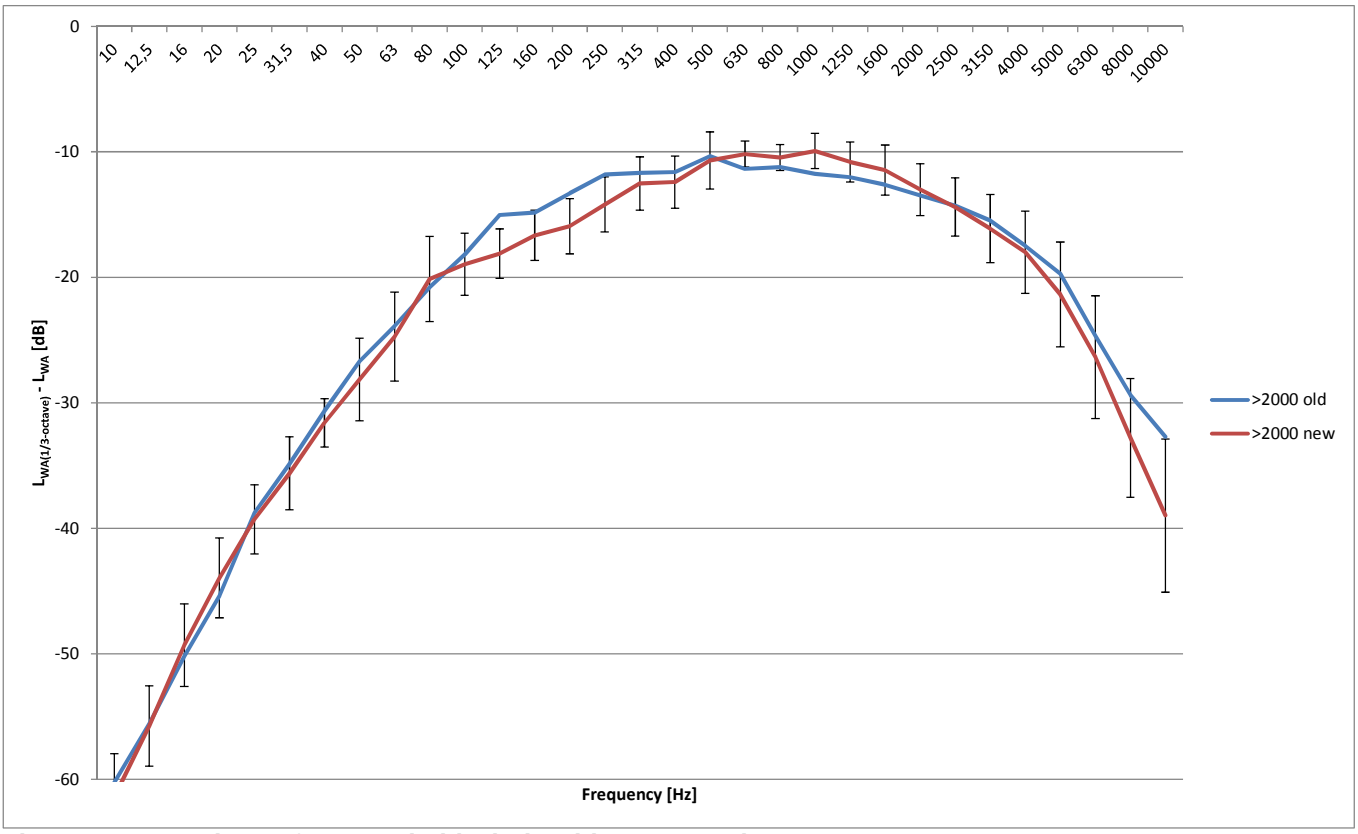

Figure 6 Comparison of new and old wind turbines > 2000 kW.

The apparent sound power level from the measurement reports are shown as a function of nominal power in Figure 7 both as the total level, L_{WA} and the low frequency part of the level, calculated as the sum of all 1/3-octave bands from 10 Hz to 160 Hz, $L_{WA,LF}$. The figure shows that the low frequency part of the level increases at a higher rate than the total level. From a regression analysis based on wind turbines with a nominal power above 200 kW the rate is 0,43 dB for each doubling of the nominal power in MW. This is a modest development compared to previous analyses of this and suggests that low frequency noise emission can be reduced.

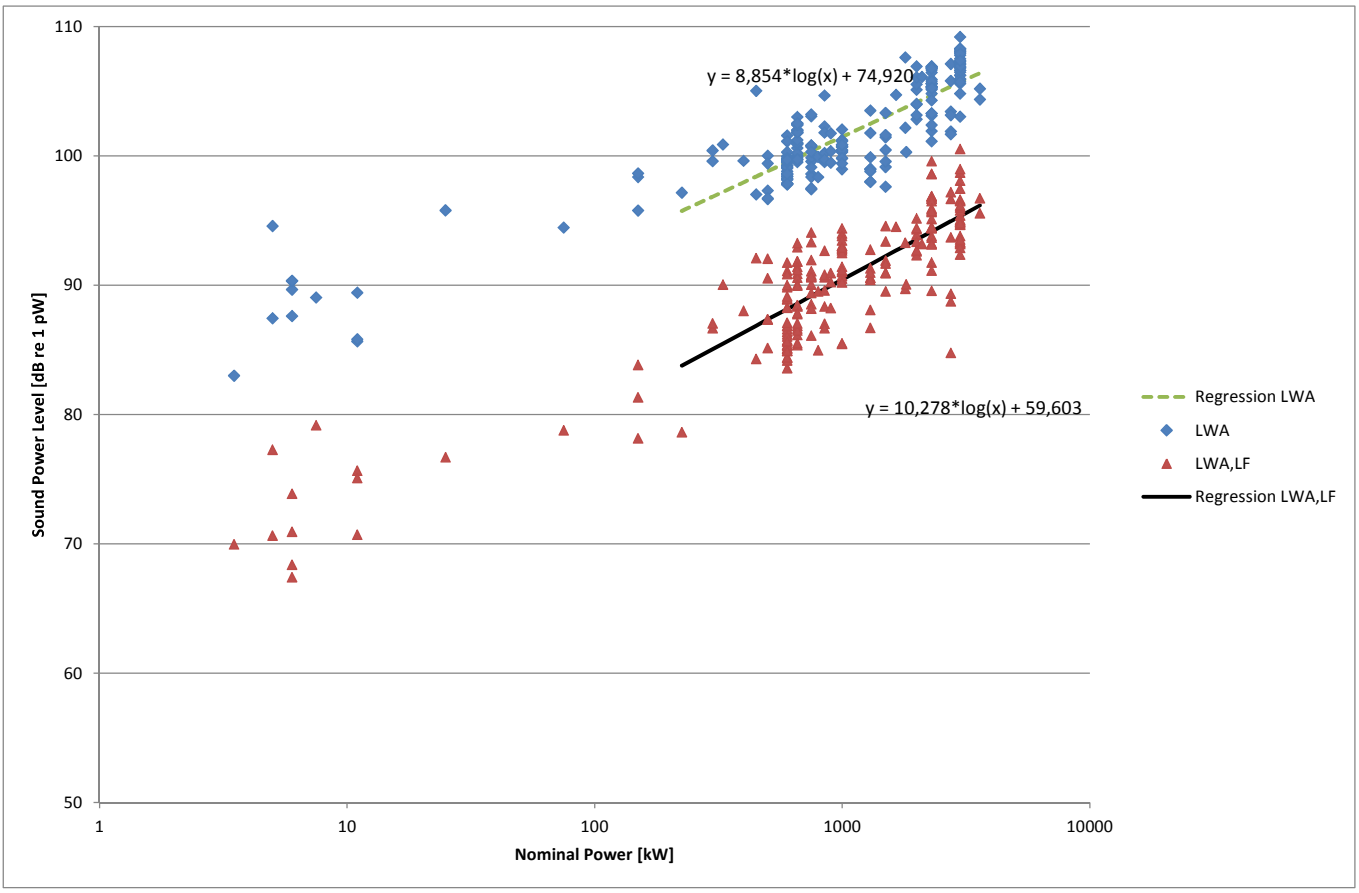

Figure 7 L_{WA} and $L_{WA,LF}$ as a function of nominal power at 8 m/s.

3.0 Other considerations

In this article as well in other reviews and presentations the basis has been the sound power level at 8 m/s. This wind speed has been the reference wind speed during the period where noise from wind turbines have been measured. This may not be fair to the new type of turbines where pitch control has taken over from stall and active stall regulation of wind turbines. Measurements where a wider wind speed range have been covered shows that the large pitch regulated wind turbines have the maximal noise emission around 8 m/s. Older wind turbines especially stall and active stall regulated wind turbines have the maximum noise emission at larger wind speeds. Sometimes the maximum may be 5 dB or more higher than the value at 8 m/s. This can be seen in Figure 8, where the noise as a function of wind speed is shown for the 3 types of regulation. For comparison the curves are normalized to 0 dB at 8 m/s. Experience from measurements show that the low frequency noise increases at approximately the same rate as the “normal” noise and older wind turbines may actually produce more low frequency noise at wind speeds above 8 m/s than the modern large pitch controlled wind turbines. Possibly neighbours have been subjected to more low frequency noise from the old turbines than they are be from the present generation of turbines.

In Figure 9 the spectra for a stall and a pitch regulated wind turbine at 10 m/s are shown. The wind turbines have comparable spectra at 8 m/s. It is obvious that the noise and the low frequency noise has increased significantly for the stall regulated wind turbine compared to the pitch regulated wind turbine.

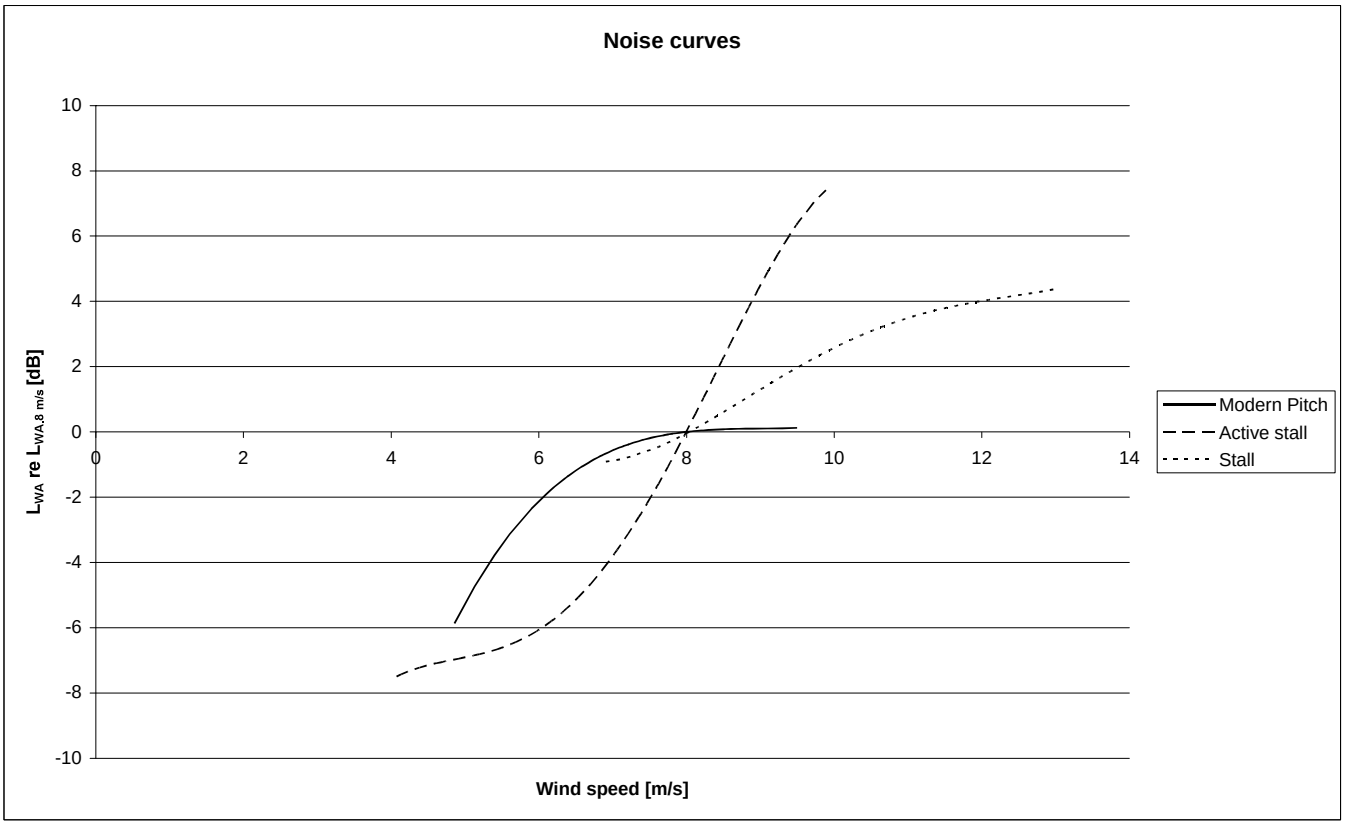

Figure 8. Noise curves for 3 types of wind turbines. The curves are normalised to pass through 0 dB at 8 m/s for comparison, but are from actual measurements.

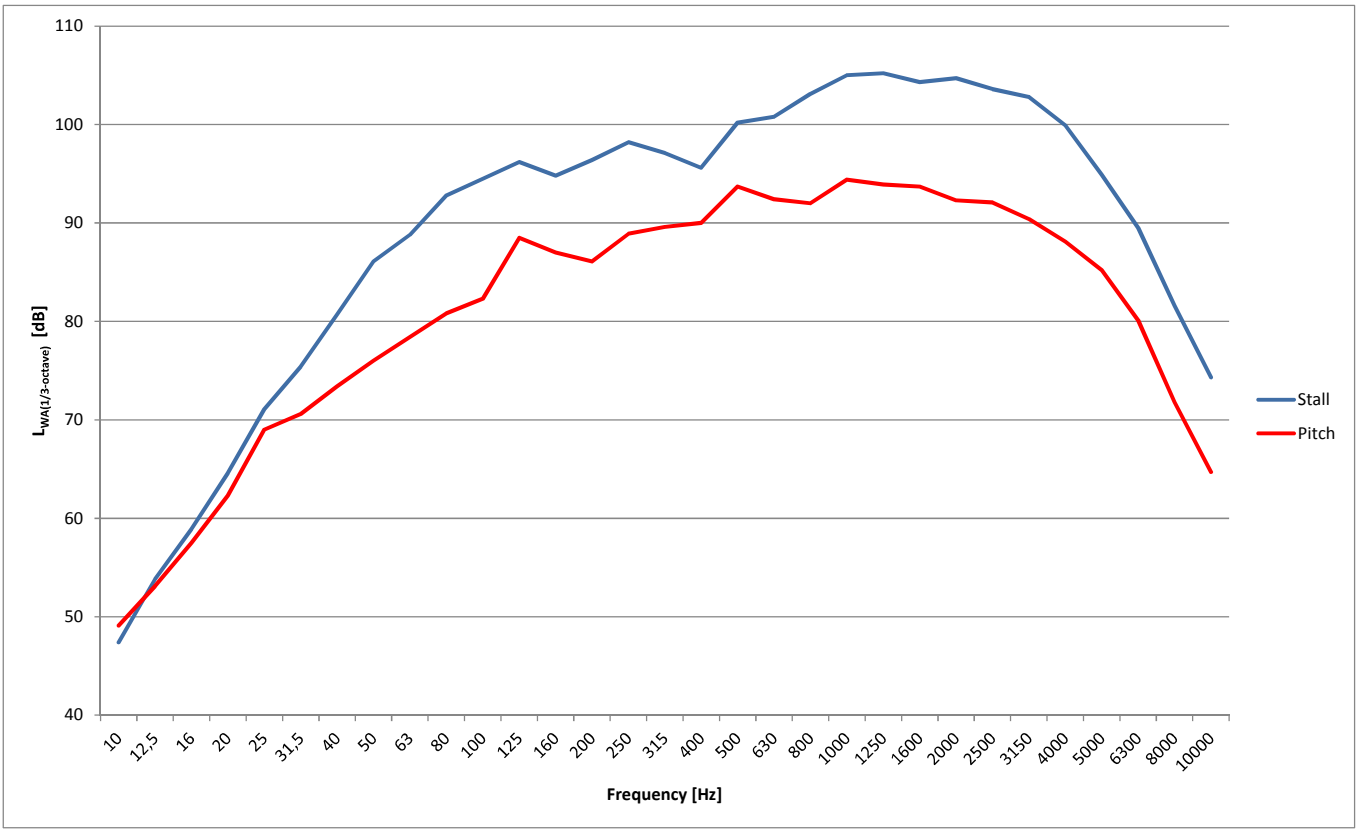

Figure 9 Spectra for comparable stall and pitch regulated wind turbines at 10 m/s.

4.0 Conclusions

The purpose of this review was to investigate if the new Danish regulation on low frequency noise have had any impact on the emitted and perceived low frequency noise. The wind farm examples does not give a clear answer. It gives the impression, that the situation has not changed and the amount of low frequency noise at the residents is the same as for wind farms with smaller and older wind turbines.

Looking at the sound power levels and sound power spectra gives a little more information. Analysis of the sound power spectra shows that after 2010 the relative amount of noise in the frequency range from 100 to 400 Hz is reduced. This includes the important part of the low frequency range from 100 Hz to 160 Hz. Whether this is because of the Danish regulation is impossible to say, but it is likely that the regulation increase the focus on this in the design phase. It is the experience of Grontmij, that the low frequency tones, which were a significant part of low frequency noise in [1], [2], [3] and [4] is reduced for commercial wind turbines.

The analysis is based on a large number of measurement reports and experiences from post construction documentation, but the results can change with more data. There is a large variation in sound power levels and sound power spectra within each class used in the analysis and it is important to check the details for each wind farm project. It is also important to follow the development into the next generation of wind turbines where new technologies are necessary.

References

[1] Søndergaard B. “Low Frequency Noise from Large Wind Turbines – Summary and Conclusions form Measurements and Methods”. AV 140/08. DELTA April 2008

[2] Madsen K. D. “Low Frequency Noise from Large Wind Turbines – Final report”. AV 1272/10. DELTA November 2010

[3] Møller H. Low Frequency “Noise from Large Wind Turbines”, Acoustics University of Aalborg June 2010 (in Danish)

[4] Møller H. Møller H. “Low Frequency Noise from Large Wind Turbines – update 2011”, Acoustics University of Aalborg May 2011 (in Danish)

[5] Statutory order 1284 of 15. December 2011 “Noise from wind turbines” from the Danish ministry of the environment (in Danish)

[6] Jakobsen J. “Danish regulation of low frequency noise from wind turbines”. 15th International Meeting on Low Frequency Noise and Vibration and its Control Stratford upon Avon UK 22nd – 24th May 2012

[7] Sørensen T. “Experiences with the New Danish Rules for the Calculation of Low Frequency Noise from Wind Turbines” 15th International Meeting on Low Frequency Noise and Vibration and its Control Stratford upon Avon UK 22nd – 24th May 2012