Fourth International Meeting on Wind Turbine Noise

Rome Italy 12-14 April 2011

Testing the new version of IEC 61400-11

Bo Søndergaard
Grontmij | Carl Bro, Acoustica, Dusager 12 DK 8200, Aarhus N, Denmark
Bo.sondergaard@grontmij-carlbro.dk

www.grontmij.dk, www.acoustica.dk

Abstract

The new version of the noise measurement standard is almost ready to be put into action. The standard is improved significantly, especially on the analysis and data treatment part. As this gives a more comprehensive and complex standard a test have been made comparing 5 independent implementations of the method described in the text. A set of test data has been prepared and the different implementations have been used on these data. This paper presents the results of this test including the possible problems with the standard. A comparison with the existing version of the standard is included as well.

Introduction

The IEC 61400-11 have already changed several times since the first version published in 1998, [1], [2], [3] and [4]. The reason for this is the major changes in the technology and scale of wind turbines. The new version as described in [5] is intended to be more generic to avoid the need for rapid changes. The target is the large wind turbines but a separate annex is dealing with small scale wind turbines. In [6] Søndergaard gives an overview of the new version. The major changes between edition 2.1 and edition 3 are:

- Higher order regression analysis is replaced with bin-analysis and the bin size is changed from 1 m/s to 0.5 m/s.
- Analysis is based on 1/3-octavebands from 20 Hz to 10 kHz
- Averaging time is 10 s previously 60 s
- The reference wind speed is at hub height
- Detailed analysis of uncertainty on the results
- All spectra are used in the tonality analysis
- An annex for small wind turbines

The changes make the standard appear more complex than the previous versions but the entire measurement procedure is basically unchanged.

The analysis and reporting procedures are changed and in order to investigate the consequences of this a set of test data was prepared and distributed to 5 parties. The results from the 5 parties should be returned and compared. However, at the

deadline for the paper only 2 sets of results were available, one from Grontmij | Carl Bro, Acoustica and one from Siemens Wind Power (SWP) and not all for all the planned tests. Some analyses and conclusions are made from these 2 data sets.

Known errors in the CDV

The following errors were identified in the CDV [5] and communicated before the tests were started.

Equation (25) describes how to correct for background noise, when the difference between total noise and background noise is less then 3 dB. The reference to background noise (index B) shall be replaced with a reference to the total noise (index T).

$$u_{c,i,k} = \frac{\sqrt{\left(u_{L_V,T,i} \cdot 10^{\left(\frac{L_{V,T,i}}{10}\right)}\right)^2 + \left(u_{L_V,B,i} \cdot 10^{\left(\frac{L_{V,B,i}-3}{10}\right)}\right)^2}}{10^{\left(\frac{L_{V,T,i}}{10}\right)} - 10^{\left(\frac{L_{V,B,i}-3}{10}\right)}} \qquad (25)$$

In equation 28 the square root in the counter shall be omitted as the equation is used for calculation of correlated uncertainties.

$$u_{L_{WA,k}} = \frac{\sqrt{\sum_{i=1}^{28}\left(u_{c,i,k}\, 10^{\left(\frac{L_{WA,i,k}}{10}\right)}\right)}}{\sum_{i=1}^{28} 10^{\left(\frac{L_{WA,i,k}}{10}\right)}} \qquad (28)$$

Test data and test plan

The test data are based on actual measurement data modified and anonymized. The data were distributed in the set of xls-files listed in Table 1. A series of comparisons were planned e.g. a comparison of edition 2 with the method in the CDV.

Test no.	Test Method	Data files	Power curve files	Comments
1	Edition 2	Test-mod_total Test-mod_back	Standard Power curve.xls	For comparison with test 2
2	Edition 3	Test-mod_total-10s Test-mod_back-10s	Standard Power curve.xls	For comparison with test 1
3	Edition 3	Test-mod_total-10s Test-mod_back-10s	Special Power curve.xls	Test of Power curve allowed range. 3% uncertainty assumed
4	Edition 3	Test-original_total-10s Test-original_back-10s	Standard Power curve.xls	Test of situation with significant background noise
5	Edition 3	Test-mod_total-10s Test-mod_back-10s	Standard Power curve.xls	Test with missing data i bin. Discard data in bin 7.5 m/s

Table 1. Test matrix and data files

The power curves are normalized to 5 MW with a standard type power curve and a special power curve with a non-typical behaviour. The power curves are shown in Figure 1. The special power curve is included for testing the new criteria in the CDV for which parts of a power curve can be used for determining the wind speed.

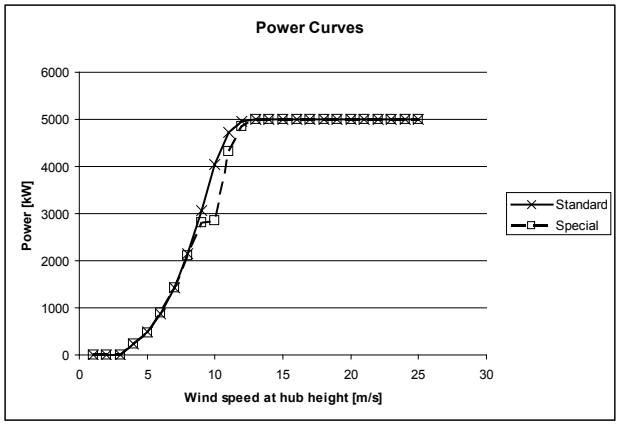

Figure 1. Power curves used in the test. The special power curve illustrates a step in the power curve which could be used in optimisation of the noise or other parameters.

The level of the noise data are scaled to a random level and the original data with significant background noise in part of the spectrum are modified to a more typical situation without significant background noise. Examples of the spectra are shown in Figure 2.

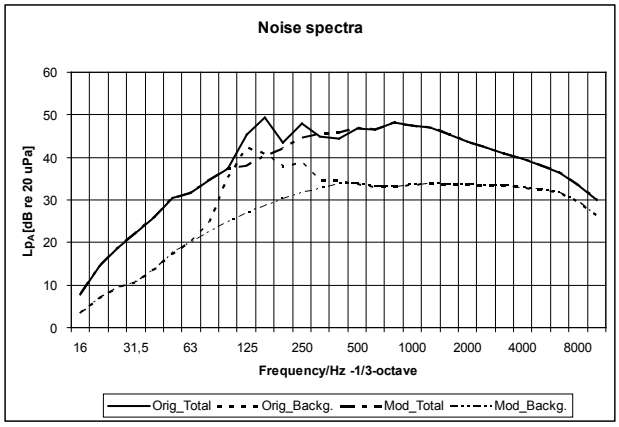

Figure 2. Example of noise spectra from the tests. Note that the original and modified spectra are identical outside the frequency range for the modification.

For calculation of the sound power levels the hub height is set to 90 m and the measurement distance to 150 m.

Values for type B uncertainties were not well defined in the test setup and SWP have not included type B uncertainties in the analyses.

The analysis consists of the following steps:

- Determining the normalised derived wind speed $V_{P,n}$ from the power and the power curve
- Determining the κ and μ factors for in-situ calibration of the nacelle anemometer and the mast mounted anemometer.
- Determining the normalised wind speeds $V_{H,n}$ and $V_{B,n}$ at hub height
- Determining the average normalised wind speeds pr bin and the number of data points pr. Bin.
- Determining the average spectra pr bin for the total noise and the background noise, and the corresponding standard deviations and covariances.
- Determining which bin averages that are to be used for calculating the individual bin centre values.
- Determining the t-factors used for interpolation between bin averages used for calculation of the bin centre values of the total noise spectra and background noise spectra. Note that the t-factor can be negative or larger than 1 corresponding to extrapolation which is allowed in certain circumstances.
- From this, calculate the sound power spectrum, the sound power L_{WA} and the corresponding uncertainties.

In the result files it should be possible to check the results of each of these steps. The κ and μ factors, the counts pr. bin and the t-values are good test-parameters. If some of these differ in a comparison, the end results are bound to be different. This would also suggest a difference in interpretation of the standard. If on the other hand these parameters are in agreement, differences in the end results are most likely due to simple errors.

Comparison between different implementations

Only the results from Siemens Wind Power and Acoustica were available and the comparisons are based only one these data sets. In general the 2 sets of analyses were in good agreement. The number of data points pr. bin were identical, the average wind speeds, the average noise level in 1/3-octave bands the standard deviations, covariances and t- values were identical to the third or fourth decimal, occasionally to the second decimal. If rounded to 1 decimal the results would have been identical. In Figure 3 to Figure 5 a graphical comparison of spectra, standard deviations and covariances are shown. Note that the curve showing the differences between the Acoustica and SWP data are much smaller than the values of the parameters, even for the covariance which in it self is very small.

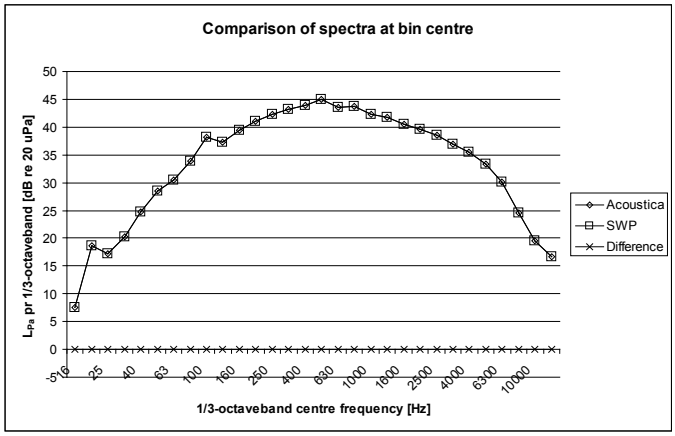

Figure 3. Comparison of bin centre spectra determined from interpolation between bin averages. This includes the effect interpolation between bins.

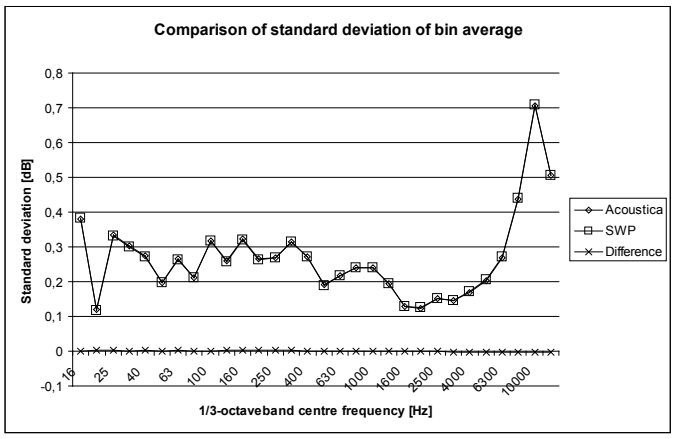

Figure 4. Comparison of standard deviation for the bin average of the total noise

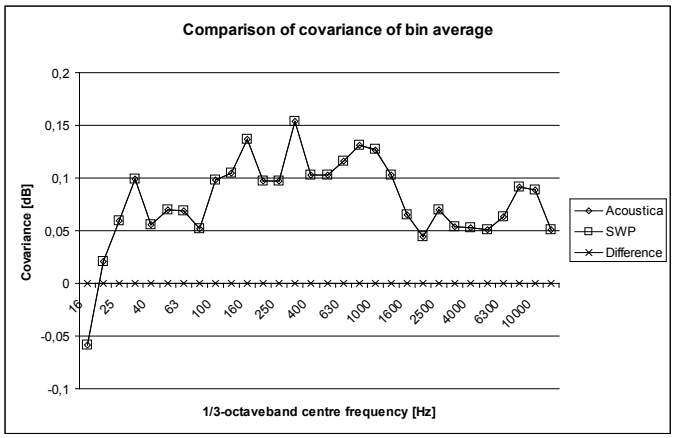

Figure 5. Comparison of the covariance of the bin average of the wind speed and the total noise.

In the comparisons with SWP data the nacelle anemometer wind speed was used for the background noise as SWP never uses a mast mounted anemometer for their internal measurements and therefore have not implemented it. This does not change the fact that the 2 implementations give similar results on identical data.

Results from complicated situations

In Figure 6 is shown what happens if significant background noise is present in part of the frequency range. The bracket around some of the data indicates that the difference between total noise and background noise is less than 3 dB and that a 3 dB corrections is used.

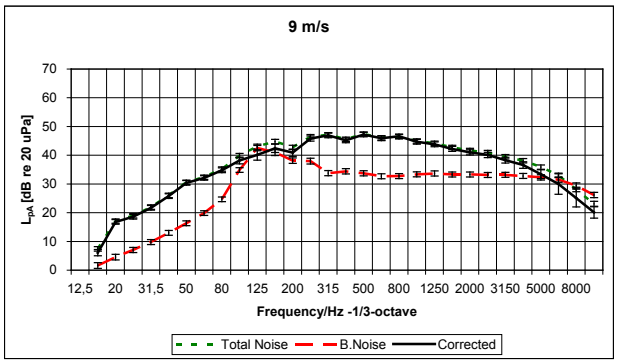

Figure 6 Results from analyse with significant background noise. If the difference between total noise and background noise is less than 3 dB, a 3 dB corrections is used. These results are marked with a bracket. Note that the uncertainty on the corrected values increase when the background noise is close to the total noise.

	LpA pr 1/3-octave [dB]		
Frequency	Total Noise	B.Noise	Corrected
12,5			
16	7,4	1,6	6,1
20	17,1	4,5	16,8
25	18,9	7,0	18,6
31,5	22,0	9,8	21,7
40	26,0	13,0	25,8
50	30,6	16,3	30,4
63	32,4	19,9	32,1
80	35,2	24,7	34,8
100	39,9	34,9	38,2
125	43,1	42,5	[40,1]
160	44,8	41,0	42,4
200	42,7	38,1	40,9
250	46,4	38,0	45,8
315	47,1	33,8	46,9
400	45,6	34,4	45,2
500	47,4	33,7	47,2
630	46,1	32,7	45,9
800	46,4	32,7	46,6
1000	45,0	33,3	44,7
1250	44,2	33,7	43,8
1600	42,7	33,3	42,2
2000	41,6	33,3	41,0
2500	40,9	33,1	40,1
3150	39,5	33,2	38,3
4000	38,1	32,8	36,6
5000	35,9	32,3	33,4
6300	33,0	31,5	[30]
8000	28,1	29,4	[25,1]
10000	23,1	26,2	[20,1]

The tests with a special power curve and with missing data were only for testing very specific parts of the standard and will not be discussed further in this paper.

Comparison with edition 2.1

This comparison is only made on the modified data representing a simple standard situation for which edition 2 can be applied and only for Acoustica data. Graphical presentations of the data are shown in Figure 7 and Figure 8. Obviously something has gone wrong with the wind speed for the background noise in Figure 8. The total noise and the background noise are measured under similar conditions intermittently during the measurement period. The wind speed range should be comparable for the total noise and the background noise. In Figure 9 the κ-factor method from edition 2 is applied to the CDV analysis, giving a more acceptable wind speed range for the background noise. None of the methods however, are giving results which intuitively seem realistic. In Figure 10 the nacelle anemometer wind speed is used. The wind speed range for the total noise and background noise is comparable which seem realistic under the given measurement conditions.

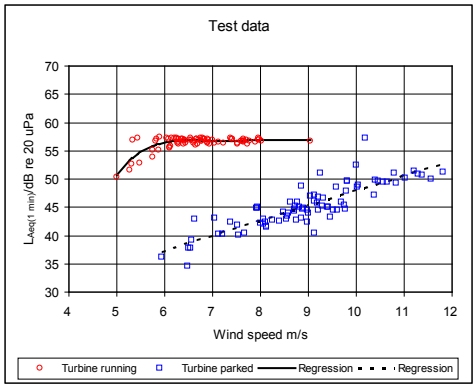

Figure 7. Noise data analysed according to edition 2. Averaging time is 60 s and the reference height for wind speed is 10 m.

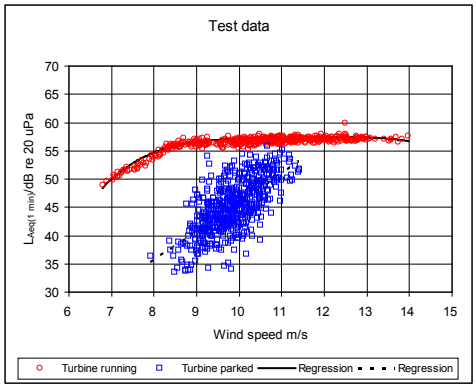

Figure 8. Noise data analysed according to the CDV. Averaging time is 10 s and the reference height for wind speed is hub height (90 m).

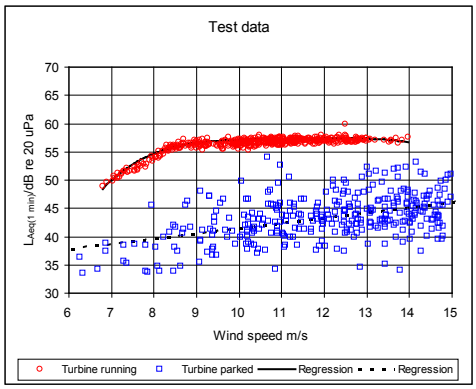

Figure 9. Noise data analysed according to the CDV. Averaging time is 10 s and the reference height for wind speed is hub height (90 m). The κ-factor method is applied instead of the κ/μ method.

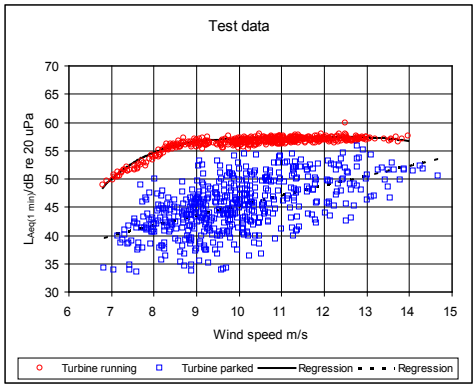

Figure 10. Noise data analysed according to the CDV. Averaging time is 10 s and the reference height for wind speed is hub height (90 m). The nacelle anemometer wind speed is applied instead of the κ/μ method.

The analysis is finished according to the text in the CDV and the results are given in Table 2. There is a reasonable agreement between the methods in the overall level for the apparent sound power level. Due to the problems with determining the wind speed for the background noise from the κ/μ method the correction for background noise is overestimated for the CDV method. The numbers in parenthesis shows the result is the κ factor method from edition 2 was used. The spectral distribution shown in Figure 11 and Figure 12 are also in agreement but a little more detail can be seen in the results determined according to the CDV, probably due to the shorter averaging time pr. spectrum.

Normalised wind speed	6 m/s	7 m/s	8 m/s
LWA,k Edition 2	106.3	106.5	106.6
LWA,k CDV	105.7	105.9 (106.1)	106.1 (106.3)

Table 2. Apparent sound power level determined form test 1 and 2 following edition 2 and the method in the CDV. The reference height for the wind speed is 10 m. The numbers in parenthesis is for an analysis where the κ factor method is used for the background noise wind speed.

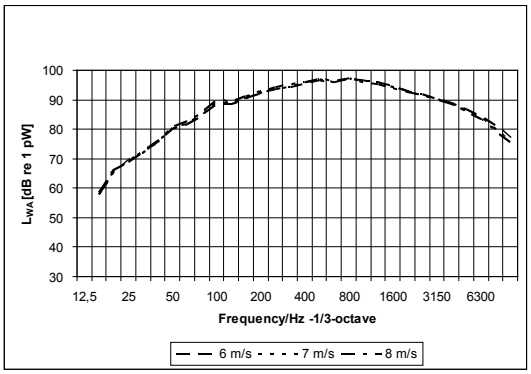

Figure 11 Sound Power spectra from analysis according to edition 2

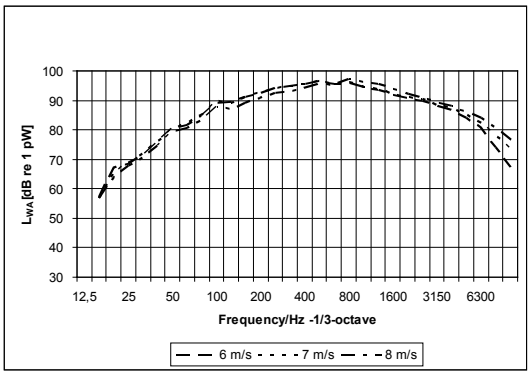

Figure 12 Sound Power spectra from analysis according 20 the CDV

Conclusions

This test was set up to see if it different implementations of the new standard would lead to different results. Only 2 sets of data were available and not for all of the planned tests. The comparison is not a proof but only an indication on whether the standard is understandable and programmable. Both at Acoustica and at Siemens Wind Power the programmer was an experienced measurement technician with a basic understanding of the purpose of the standard. The programmers were not given any guidance from the persons at the companies involved in developing the standard. It is most likely that persons with no prior knowledge in the field may have problems understanding the principles of he standard but that goes for many standards. This test shows that persons with basic understanding of this type of work will be able to understand and set up the data analysis correctly.

The test also shows that the κ/μ method apparently does not work for the mast mounted anemometer and possibly will have to be changed.

The new standard is able to deal with situations where edition 2 of the standard cannot give results e.g. with high background noise and with power curves with at stepwise character. This type of power curves can be realized due to optimised operations of wind turbines or wind farms and have to be considered.

The group behind the test is considering making the test data and results, when finished, available for others if the CDV passes the next phase. The group behind the test is:

Grontmij | Carl Bro Acoustica, Siemens Wind Power, Vestas Wind Systems, Suzlon Wind Energy and DELTA.

References

[1] IEC 61400-11:1998 Wind turbine generator systems – Part 11: Acoustic noise measurement techniques

[2] IEC 61400-11:2002 edition 2 Wind turbine generator systems – Part 11: Acoustic noise measurement techniques

[3] IEC 61400-11:2002 ammendment 1:2006 Wind turbine generator systems – Part 11: Acoustic noise measurement techniques

[4] IEC 61400-11:2002 edition 2.1 Wind turbine generator systems – Part 11: Acoustic noise measurement techniques.

[5] 88/384/CDV IEC 61400-11 edition 3 Wind turbine generator systems – Part 11: Acoustic noise measurement techniques. 2010-11-26

[6] Søndergaard B. (2009), The next version of the IEC 61400-11 measurement method, Third International Meeting on Wind Turbine Noise Aalborg Denmark 17 – 19 June 2009