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

The new good-practice-guide to help assessment of wind turbine noise in Finland

Denis Siponen (1)**, Carlo Di Napoli** (2)**, Raimo Eurasto** (1)**, Veli-Matti Yli-Kätkä** (3), **Seppo Uosukainen** (1), **Hannu Nykänen** (1),

(1) VTT Technical Research Centre of Finland
(2) Pöyry Finland Oy
(3) Ramboll Oy

Abstract

National regulations regarding wind turbine noise levels are currently missing in Finland. Since wind power production in Finland is planned to increase from 220 MW to 3750 MW by 2025, many regulatory authorities, project developers and environmental offices from local municipalities demanded new and harmonised guidance regarding wind turbine noise. The Finnish Ministry of Environment published new guideline $L_{A,eq}$ noise levels for wind turbine noise in summer 2012. However these guidelines did not include detailed guidance for propagation modelling or general assessment methods of wind turbine noise. In the end of 2012, a joint-funded “Tuulivoimamelu” -project was started. Object of this project was to create a good-practice-guide for wind turbine noise modelling, guide for measuring the compliance levels and also assessment of annoyance of wind turbines. New features include the phasing of the propagation modelling in two parts (in addition to preliminary modelling by the project developer) roughly following the national land use planning phases and include a comprehensive compliance noise measurement guide in Finnish language. The project was joint-funded by the Finnish Ministry of Environment, the Finnish Wind Power Association and the Finnish Energy Industries.

1. Introduction

Finland intends to increase the share of renewable energy to 38 per cent of total energy consumption by year 2025. For wind power this means increasing the production to at least 3750 megawatts from the current figure, which is approximately 220 megawatts (2012) (Ministry of Environment, 2012). Locations of power plants are determined primarily by techno-economical factors as well as the environmental values of those areas and their other use.

In October 2012, Finnish Ministry of the Environment, Finnish Energy Industries and Finnish Wind Power Association started a project in order to create detailed guidelines to apply the design reference values for wind power noise specified in 'Tuulivoimarakentamisen suunnitteluopas'. (Ministry of Environment, 2012) This project is known as TUULIVOIMAMELU (**‘**Wind farm noise**’**). It is realized primarily by VTT, with Pöyry Finland Oy and Ramboll Finland Oy being the other two involved parties.

The noise generated by wind turbines may differ characteristically from sounds generated by other sources, such as traffic and its perceived disturbance may also differ. For this reason, wind farms require separate measurement and verification guidelines. To counter the adverse effects of noise in a cost-effective fashion, the selected methodology should support applying the design reference values included in ‘Tuulivoimarakentamisen suunnitteluopas’ (Design guide for wind energy building), a paper released by the Finnish Ministry of Environment in July 2012.

2. Comparison of different calculation parameters with various modelling programs

One part of the “Tuulivoimalamelu”-project was to test behaviour of some noise abatement programs with different calculation parameters. The motivation of this was to find possible differences between programs and more importantly, sensitivity of various parameters to calculation results with these results, educated opinion could be given on what parameter values should be used in modelling. In comparison, 11 different modelling cases were made using a pre-planned wind farm area in northern Finland. Compared noise abatement programs and used propagation models were:

- CadnaA, ISO 9613-2
- WindPro, ISO 9613-2
- SoundPlan, ISO 9613-2 ja Nord2000

In Scandinavia, ISO 9613-2 is widely used standard for outdoor industrial noise propagation calculation. This propagation model is relatively simple but has several drawbacks. For example, it does not account wind speed or direction in its calculations. It is also debated should it be used for calculating wind turbine noise propagation at all, since it is designed for relatively static noise sources such as industrial facilities.

Nord2000 is also found to be commonly used in Scandinavia (as it also is a joint Scandinavian project) and at least two commercially available software’s have included the algorithm. Nord2000 has many advantages since it’s development is based on a more complex algorithm with more options for taking account environmental factors such as temperature and wind gradients.(Kragh, Plovsing, 2001)

2.1 Initial data

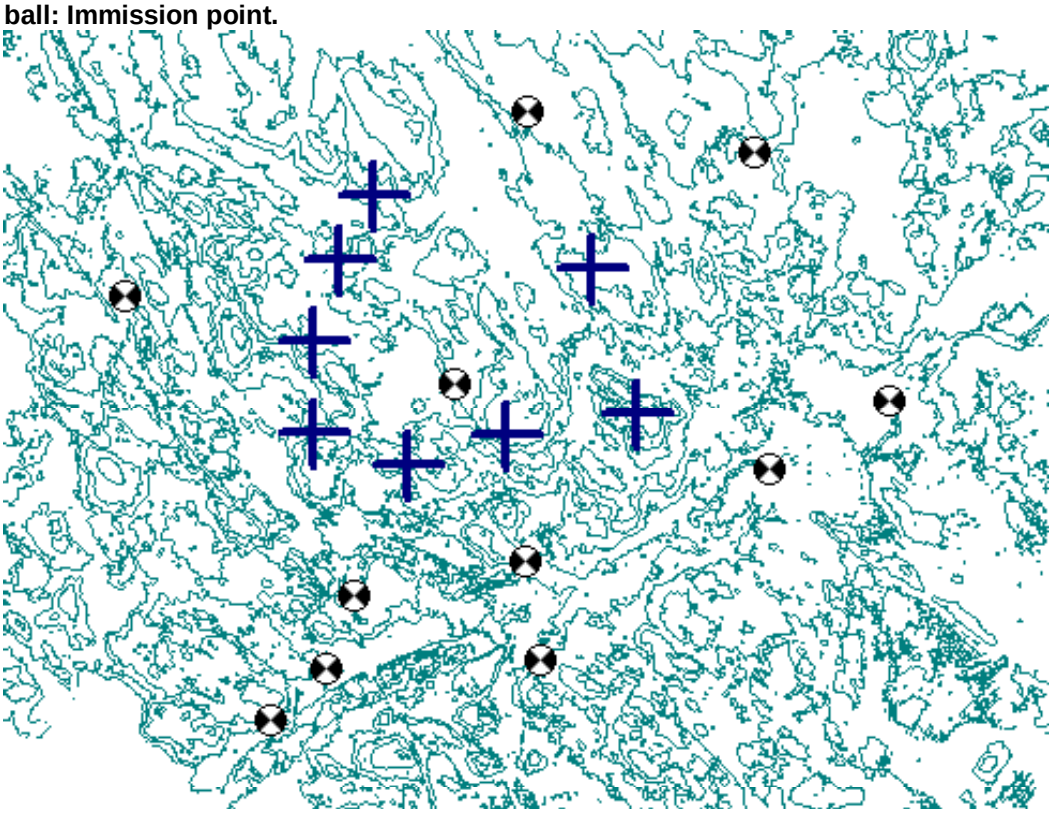
Existing wind farm used in modelling cases consists of eight Vestas V112 wind turbines. Hub height of these wind turbines is 140m and length of rotor 56m. They were modelled as a point source, 140m above ground. Because sound power level of this wind turbine type was not generally available, same data found from literature was used instead (Moller, 2011). This sound power level data was with wind speed of 8 m/s and for these levels, 0.5 dB error margin was added (Moller et. Al., 2011). Octave levels of this sound power data is shown in table 1 below.

Table 1. Sound power data of Vestas V112 in wind speed of 8 m/s in octave bands.

Octave band [Hz]	31.5	63	125	250	500	1000	2000	4000	8000	TOT
dBA	77.7	90.4	95.9	96.5	99	101.8	99.7	94.8	87	106.5

For the modelling cases, 11 immission points were chosen all around the wind farm nearest being at 430 m and furthest 1700 m from near-by wind farm. Topological layout of emission and immission points used in modeling are shown in figure 1.

Figure 1: Topological layout of emission and immission points used in modeling. Cross: Emission point, ball: Immission point.



Accounting wind speed and direction in noise propagation calculation varies greatly between propagation models. In Nord2000-model, both of these parameters are taken in account in calculations but in ISO 9613-2, it is not possible. Therefore it was decided that wind speed and direction is not taken account at all in modelling cases, because that was the only way to unify wind conditions between used noise propagation models. It must be noticed that wind speed and direction is already taken into account indirectly in used emission level of wind turbine (8 m/s downwind in 10m height). Air temperature and humidity was kept at their ISO9613-2 default values, 15'C and 70%.

2.2 Comparison between programs and propagation models with default values

Calculated noise levels in immission points with default parameter values are shown in table 3. Default parameter values are:

- Horizontal resolution of topography: 0.5 m
- Ground asorption G: 0
- Relative height of immission point: 2 m
- Air temperature: 15'C
- Air humidity: 70%

Table 2: Calculated noise levels in immission points with default parameter values.

Immission point	A-weighted noise level [dB]			
	CadnaA (ISO 9613-2)	WindPro (ISO 9613-2)	SoundPlan (ISO 9613-2)	SoundPlan (Nord2000)
1	39.9	39.8	39.7	40.0
2	36.2	36.2	35.8	38.6
3	38.6	38.5	38.3	38.6
4	47.3	47.2	47.3	46.1
5	34.1	34.0	33.6	34.8
6	37.8	38.8	38.4	37.9
7	42.1	42.0	42.0	42.3
8	40.9	40.9	40.8	40.2
9	37.1	37.1	36.8	37.4
10	37.3	37.2	36.8	37.1
11	34.6	34.5	33.7	34.6

As from table 2 can be seen, differences between programs with same propagation model (ISO 9613-2) are quite small (up to 1 dB) However, comparing ISO 9613-2 and Nord2000, even within same program, differences are noticeably larger (up to 2.8 dB).

2.3 Comparison between modelling programs, ISO 9613-2

In tables 4 and 5 comparison between three different modelling programs with ISO 9613-2 is shown. Results are displayed so that values represented in specific colour means that values are that much higher with program in same colour compared to other program. For example: If CadnaA is coloured as red and WindPro as blue (as in table 4), then if a given value is 0.7 in blue colour, calculation result done with WindPro is 0.7 dB higher than with CadnaA.

All 11 different modeling cases with their single varied parameters are shown in table 3.

Table 3: Modeling cases

Case	Varied parameter
1	Initial parameters
2	Vertical resolution of topography: 1 m
3	Vertical resolution of topography: 2.5 m
4	Ground absorption G: 0.25
5	Ground absorption G: 0.5
6	Relative height of immission point: 2 m
7	Air temperature: T = 0 °C
8	Air Humidity: Rh = 30 %
9	Relative height of immission point: 2 m, Ground absorption G: 0.5

As can be seen from table 4 and 5, calculation result differences between programs are generally small. Comparing CadnaA and WindPro, differences are neglible in all immission points except point 6 where there is almost coherent difference between programs. This is most probably due to differences in algorithms how terrain data is formed from topology height curves. When comparing SoundPlan to CadnaA or WindPro, SoundPlan calculates systematically up to 1.3 dB higher values than other two programs. Reason for this behaviour is unknown.

Table 4 (left): Comparison between CadnaA and WindPro programs with different modelling cases. Table 5 (right): Comparison between WindPro and SoundPlan programs with different modelling cases.

CadnaA (ISO 9613-2)					vs.	WindPro (ISO 9613-2)				
Immission point										
1	2	3	4	5	6	7	8	9	10	11
Vertical resolution of topography = 0.5 m										
0.1	0.0	0.1	0.1	0.1	1.0	0.1	0.0	0.0	0.1	0.1
Vertical resolution of topography = 1 m										
0.1	0.0	0.1	0.1	0.1	1.0	0.1	0.0	0.0	0.1	0.0
Vertical resolution of topography = 2.5 m										
0.1	0.1	0.1	0.1	0.1	0.0	0.1	0.0	0.0	0.1	0.0
Ground absorption G = 0.25										
0.0	0.1	0.1	0.1	0.1	0.7	0.1	0.0	0.0	0.1	0.0
Ground absorption G = 0.5										
0.0	0.0	0.0	0.0	0.1	0.4	0.0	0.0	0.1	0.0	0.0
Height h = 4 m										
0.1	0.1	0.1	0.1	0.1	0.9	0.1	0.0	0.0	0.1	0.1
Air temperature t = 0'C										
0.1	0.0	0.1	0.0	0.1	1.1	0.1	0.1	0.1	0.0	0.1
Air relative humidity Rh = 30%										
0.0	0.0	0.1	0.0	0.0	1.1	0.0	0.0	0.0	0.0	0.1
Height h = 4 m, ground absorption G = 0,5										
0.1	0.1	0.1	0.0	0.1	0.3	0.0	0.1	0.1	0.1	0.0

WindPro (ISO 9613-2)					vs.	SoundPlan (ISO 9613-2)				
Immission point										
1	2	3	4	5	6	7	8	9	10	11
Vertical resolution of topography = 0.5 m										
0.1	0.4	0.2	0.1	0.4	0.4	0.0	0.1	0.3	0.4	0.8
Vertical resolution of topography = 1 m										
0.1	0.3	0.2	0.0	0.3	0.3	0.0	0.1	0.4	0.4	0.8
Vertical resolution of topography = 2.5 m										
0.1	0.3	0.2	0.1	0.4	0.2	0.1	0.0	0.3	0.1	1.3
Ground absorption G = 0.25										
0.2	0.3	0.2	0.1	0.4	0.4	0.0	0.1	0.3	0.4	0.8
Ground absorption G = 0.5										
0.2	0.4	0.3	0.0	0.4	0.4	0.1	0.1	0.3	0.4	0.8
Height h = 4 m										
0.1	0.3	0.1	0.1	0.3	0.1	0.0	0.0	0.2	0.1	0.5
Air temperature t = 0'C										
0.1	0.4	0.2	0.0	0.4	0.4	0.0	0.0	0.3	0.4	0.7
Air relative humidity Rh = 30%										
0.2	0.4	0.2	0.0	0.5	0.4	0.1	0.1	0.3	0.4	0.8
Height h = 4 m, ground absorption G = 0,5										
0.1	0.3	0.1	0.0	0.3	0.1	0.0	0.0	0.2	0.1	0.5

2.4 Comparison between modelling cases

In table 6 comparisons between modelling case results calculated with CadnaA and ISO 9613-2 is shown. As can be seen that ground factor G is the only parameter which has noticeable effect in calculation results. This effect is up to 2.7 dB in favour to ground absorption 0 compared to 0.5. Modeling case results calculated with WindPro and SoundPlan using ISO 9613-2 resulted near identical results with CadnaA and thus are not presented here.

Similar results, only calculated with SoundPlan using Nord2000 is shown in table 7. It can clearly be seen that while overall results are generally similar, there is noticeably more variation in results between different immission points. This indicates how much more advanced and detailed Nord2000 is compared to ISO 9613-2. This however, does not indicate that Nord2000 necessarily gives more accurate results compared to real world.

Table 6 (left): Comparison between modelling cases, calculated with CadnaA using ISO 9613-2. Table 7 (right): Comparison between modelling cases, calculated with SoundPlan using Nord2000.

Immission point										
1	2	3	4	5	6	7	8	9	10	11
Topography 0.5 m					vs.	Topography 2.5 m				
0.0	0.1	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.1
Topography 0.5 m					vs.	Topography 1 m				
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1
Topography 1 m					vs.	Topography 2.5 m				
0.0	0.1	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0
Ground absorption G = 0.25					vs.	Ground absorption G = 0				
1.4	1.3	1.3	1.2	1.4	1.0	1.3	1.3	1.4	1.4	1.5
Ground absorption G = 0.5					vs.	Ground absorption G = 0				
2.6	2.6	2.6	2.3	2.7	1.9	2.5	2.5	2.6	2.7	2.8
Ground absorption G = 0.5					vs.	Ground absorption G = 0.25				
1.2	1.3	1.3	1.1	1.3	0.9	1.2	1.2	1.2	1.3	1.3
Height h = 4m					vs.	Height h = 2m				
0.0	0.1	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0
Air temperature t = 0'C					vs.	Air temperature t = 15'C				
0.0	0.2	0.1	0.3	0.3	0.1	0.1	0.0	0.2	0.1	0.3
Relative humidity Rh = 30%					vs.	Relative humidity Rh = 70%				
0.7	0.6	0.6	0.7	0.6	0.7	0.7	0.6	0.6	0.7	0.6
h = 4 m, G = 0,5					vs.	h = 2 m, G = 0				
1.9	1.9	1.9	1.8	2.0	1.2	1.9	1.8	1.9	2.0	2.1

Immission point										
1	2	3	4	5	6	7	8	9	10	11
Topography 0.5 m					vs.	Topography 2.5 m				
0.8	2.3	0.2	1.0	0.0	1.9	0.0	1.2	0.3	0.2	0.7
Topography 0.5 m					vs.	Topography 1 m				
0.2	2.3	0.1	0.1	0.1	0.0	0.1	0.3	0.3	0.1	0.2
Topography 1 m					vs.	Topography 2.5 m				
1.0	0.0	0.3	0.9	0.1	1.9	0.1	0.9	0.6	0.1	0.5
Ground absorption G = 0.25					vs.	Ground absorption G = 0				
1.1	2.6	1.8	0.4	2.4	1.3	1.5	0.9	2.1	1.5	1.9
Ground absorption G = 0.5					vs.	Ground absorption G = 0				
1.7	4.2	2.3	0.7	3.3	1.9	2.4	1.4	2.7	1.9	2.6
Ground absorption G = 0.5					vs.	Ground absorption G = 0.25				
0.6	1.6	0.5	0.3	0.9	0.6	0.9	0.5	0.6	0.4	0.7
Height h = 4m					vs.	Height h = 2m				
0.7	2.5	0.9	0.2	0.9	0.4	0.5	0.3	0.8	0.2	0.9
Air temperature t = 0'C					vs.	Air temperature t = 15'C				
0.2	0.2	0.1	0.1	0.0	0.0	0.2	0.1	0.2	0.1	0.1
Relative humidity Rh = 30%					vs.	Relative humidity Rh = 70%				
0.5	0.7	0.7	0.6	0.7	0.6	0.6	0.6	0.7	0.8	0.7
h = 4 m, G = 0,5					vs.	h = 2 m, G = 0				
2.1	4.2	2.2	0.5	3.5	0.9	2.0	1.8	3.0	1.8	2.8

2.5 Advanced parametric study with SoundPlan using Nord2000

I addition to program and parametric comparison with ISO 9613-2 which is described in previous chapters, advanced parametric study with SoundPlan using Nord2000 was conducted. Overall parametric study was made from topics listed below:

- Possible sound level difference in immission point when emission is either point or line source
- Various parameters: ground flow resistivity, wind speed, vertical temperature gradient, ground roughness factor, air turbulence.
- Combined effect of ground impedance and weather parameters

Results of source type study indicated that there is no noticeable in immission levels whether source is modelled ad point source or line source. These results are convergent and logical with theoretical analogy; immission points are distant enough from line sources and can be reduced into point sources.

Parametric study results indicated that highest A-weighted results are obtained with parameter values ground flow resistivity class G, horizontal temperature gradient dT/dZ = 0 and wind speed = 0 m/s. There was, however some incoherency in some other results when using ground flow resistivity class G with upwind situation and horizontal temperature gradient dT/dZ = 0, when wind speed changes. Also A-weighted sound levels were larger with negative horizontal temperature gradient dT/dZ than dT/dZ = 0.

When using ground flow resistivity factor E, changing weather parameters produced more logical results. However, there was still some unexplained incoherency when varying ground roughness factor and wind speed.

3. General assessment method for wind turbine noise modeling

The assessment method (modeling logic) of sound propagation emitted from wind turbines is described in the part of the guide. After a comprehensive review and comparison of different

noise models and modeling software's (see chapter 2), it was decided to go forward in guidance by using a two phase modeling logic where ISO 9613-2 standard would be the primary modeling assessment method and Nord2000 in case of environmental permitting phase. The reason for a possible double phase approach comes from the fact that all available commercial software typically used in wind farm noise modeling have ISO 9613-2 implemented.

Evaluation of environmental effects is based on the 'upper limit review' meaning that sound propagation calculation results should be presented with maximum sound emission values. This would not restrict the wind farm investor to present noise restricted operational charts such as with different turbine noise modes included, but the upper limit review presentation would set a consistent modeling logic to all wind farm planners. It is the authority's decision then to decide, wheatear an additional environmental permit should be applied to the project, if zoning of a planned wind farm/single turbine becomes difficult.

When planning a single power plant or a wind farm, noise related planning and noise modeling in Finland are carried out in at least three different stages. Noise assessment report must be included in the application documents along with other information.

Stage 1. During preliminary planning project initiator drafts an estimate for the maximum size and number of turbines to be installed taking also into account the noise emission of single turbines.

Stage 2. During zoning and evaluation of environmental effects (e.g. EIA), specific information about all turbines (with alternatives) must be provided (number of turbines, power output, height, rotor diameter, noise emission values) to be used in modeling in order to evaluate noise effects.

Stage 3. During building permit phase the selected option must now be known. The final evaluation by noise modeling is possible only at this stage.

These stages would be calculated according to ISO 9613-2 standard (Phase I modeling). In G-P-G report noise modeling is examined only for stages 2 and 3. Noise modeling of stage 1 is entirely up to project realizer, but is expected that stages 2 and 3 require following certain procedures due to permit proceedings. It is of course advisable that well prepared guidelines are followed already in the first stage to ensure consistent results during the entire project.

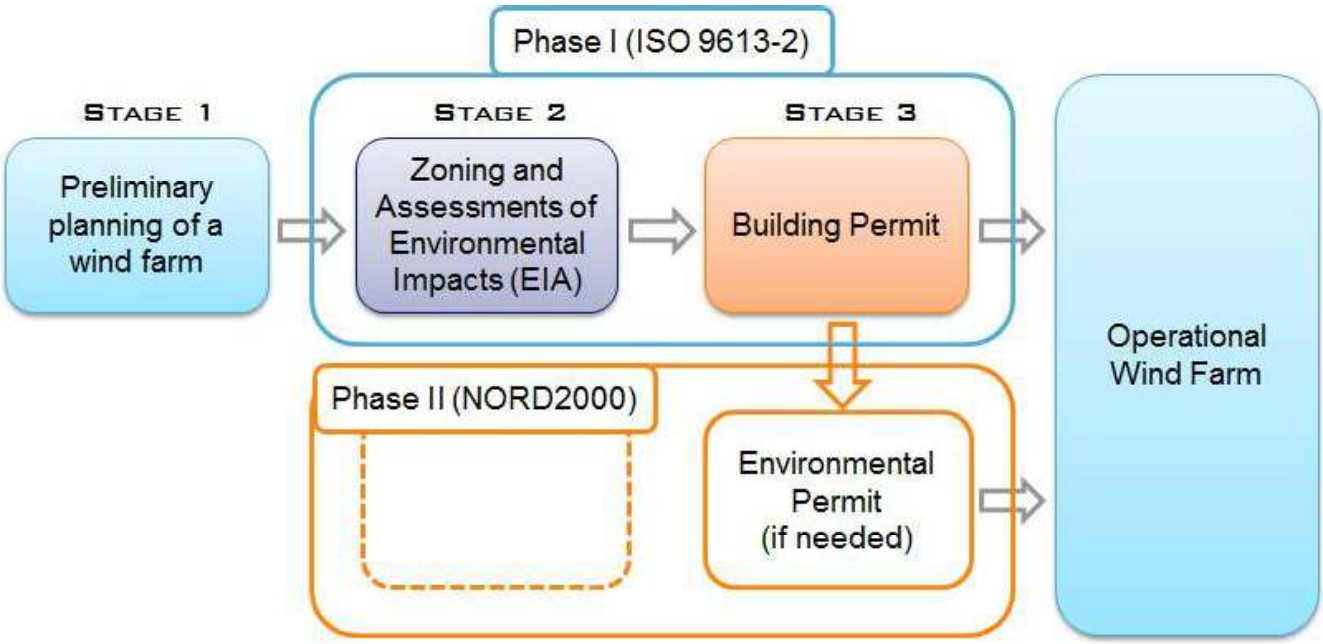


Figure 2. Schematic diagram of the procedure for different sound propagation modelling phases

As some wind farm projects may require an additional Environmental Permit to be applied (e.g. for zones that need more efficient planning design) due to control requirements of environmental impacts, the second modeling phase is designed to improve the accuracy of the propagation modeling by applying a Nord2000 propagation modeling with extended parameterization. This may include the usage of wind statistics, usage of a more accurate digital map resolution etc. The permit may include additional limits for sound emission and may require a preliminary plan for a noise optimized drive (noise modes) schedule and parameters.

The second modeling phase also includes a new noise annoyance assessment method, where a more profound sound quality assessment is required. This may include the assessments of excess amplitude modulation and impulsive noise. Low frequency noise calculations must be performed in both phases regardless of the permitting application.

3.1 Noise emission details

During the planning phase of a single power plant or a wind farm, turbine sound power information (noise emission details) is usually declared by proposed turbine supplier. It is imperative that only characteristic or declared values (warranted level) measured according to IEC 61400-11 (IEC, 2006, 2012) and reported by the manufacturer are used as the basis for modeling. Sound power levels are reported by octaves at middle frequencies 63 – 8,000 Hz or by one-third octaves at middle frequencies 20 Hz or 50Hz – 10,000 Hz. Sound power levels should be available with wind speeds corresponding to the reference height at 8 m/s and 10 m/s. It is often difficult to determine the possible tonality, impulse-like qualities or temporally fluctuating variation (amplitude modulation) of noise. Manufacturers do not necessarily provide those details unless specifically asked to do so. The constructor must therefore ensure that all information is available. The fact that there are no generally accepted (standardized) instructions for determining amplitude modulated sound provides an additional challenge.

The basis for calculation logic is therefore the declared value of power plant's noise emissions, stated by the manufacturer. In ISO 7574 (ISO, 1985), the international series of standards concerning noise emissions of products or product ranges, statistical acceptability is specified so that product range is accepted for markets (found approvable in possible verification) if there is 95 % certainty that no more than 6.5 % of products exceed the manufacturer's declared value for noise emissions. Standard IEC 61400-14 (IEC, 2005) describes, in simpler terms than ISO 7574, how characteristic or declared noise emission values can be derived from measurements made according to IEC 61400-11 in such a way that in the possible verification (i.e. confirming the accuracy of the value) the certainty for approval is approximately 95 %.

The uncertainty of modeling is included in the turbine noise emission used in the calculation. When modeling, the certainty of turbine noise emission must therefore be sufficient (characteristic or declared value reported by the manufacturer, whose certainty in verification of noise emission is at least 95 %). When that is the case, ISO 9613-2 compliant 'standardized' values for weather and environmental values can be used as target and design reference values in modeling.

3.2 Calculation parameters

To ensure consistent modeling results with different projects (e.g. in the same zoning area) sound propagation modeling phases require guidance of additional modeling parameterizations. There are known weaknesses of ISO 9613-2 when modeling wind farms but sensitivity analysis also revealed that Nord2000 parameters may also require some guidance due to some illogical results found. Although some issues are still under discussion about some minor parameterization values to be included when writing of this paper, the main parameters are presented in a table below:

Table 8. Sound propagation calculation parameters

Phase I with ISO 9613-2	
Sound emission data	Guaranteed value or Declared value (IEC 61400-14)
Ground absorption	Flat country areas, fields, forest areas: 0.4
	Hard surfaces such as water areas: 0
	Hilly areas/concave slopes: 0
Air absorption	ISO 9613-1, T= 15 C, RH = 70%
Calculation grid height	2 m (if ground absorption 0), 4 m in other cases
Contour line resolution	2.5 m vertically and 1 m horizontally
Wind direction	Omnidirectional calculation, no directivities
Weather corrections	Not applied
Tonalities	IEC 61400-11 Ed 2.2 and/or 3.0
Amplitude Modulation	Not applied
Phase II with NORD2000	
Sound emission data	Guaranteed value or Declared value (IEC 61400-14)
Ground absorption	According to real ground impedance, parameters from A-G
Air absorption	ISO 9613-1, T= 15 C, RH = 70%
Calculation grid height	2 m
Contour line resolution	0.5 m vertically (only if laser scanned ground contour data is available, otherwise the with the maximum resolution available) and 1 m horizontally
Wind direction	From wind statistics (the New Finnish Wind Atlas or measured values)
Weather corrections	Neutral or stable atmospheric states
Tonalities	IEC 61400-11 Ed 2.2 and/or 3.0
Impulsiveness	ISO 3744
Amplitude Modulation	According to Zwicker (Fluctuation strength) (Zwicker, H. 1999)

The G-P-G for sound propagation modeling phases I and II also includes guidelines on how to calculate low frequency noise as point-to-point calculation. The procedure will roughly follow the new Danish guidelines DSO 1284 (some details are under still under discussion). Information regarding the depth of the emitted amplitude modulation may be difficult to obtain from any official IEC 61400-11 test reports or sound guarantees, however an analysis regarding the potential modulation annoyance according to Zwicker et al. should be included.

4. Summary

National regulations regarding wind turbine noise levels are currently missing in Finland. Since wind power production in Finland is planned to increase from 220 MW to 3750 MW by 2025, many regulatory authorities, project developers and environmental offices from local municipalities demanded new and harmonised guidance regarding wind turbine noise. In the end of 2012, a joint-funded “Tuulivoimamelu” -project was started. Object of this project was to create a good-practice-guide for wind turbine noise modelling, guide for measuring the compliance levels and also assessment of annoyance of wind turbines. The project included sound propagation modelling comparisons, sensitivity analysis for Nord2000 propagation model (included in a Master Thesis work), parameterizations of different modelling phases and also basic guides for compliance measurements.

Modelling comparisons indicated that result differences between software’s by using the same calculation standard are generally negligible. Nord2000 is a highly developed calculation algorithm where ground effect is calculated by using more sophisticated methods and direct comparison between different ISO results (especially between different octave bands) was therefore difficult. Generally Nord2000 results are in good agreement between measured and calculated values (Delta, 2011). Therefore it was decided to split the noise calculations into two phases, where the first phase with ISO 9613-2 calculations is designed to serve most of the

wind farm projects from preliminary planning stage to the stage where the application of the building permit is prepared. The second phase with Nord2000 is designed only to those projects (applications) that need to apply an additional environmental permit due to limitations in zoning areas or where special noise control measures needs to take into account. The g-p-g then gives guidance in different modelling parameterizations in different modelling phases. This project also included guidance to perform compliance noise measurement in wind farm projects, but that part was not discussed in this document in detail.

References

The Finnish Ministry of the Environment. Helsinki 2012. *Tuulivoimarakentamisen suunnittelu. Ympäristöhallinnon ohjeita 4* | *2012*. 92 pages

Kragh, J. Plovsing, B. Storeheir, S. Jonasson, H. Nordic Environmental Prediction Methods, Nord2000, Summary Report. General Nordic Sound Propagation Model and Applications in Source-Related Prediction Methods. Delta, 2001.

Sondergaard, B. Plovsing, B. Validation of the Nord2000 propagation model for use on wind turbine noise. Delta, Denmark 2009.

ISO 7574-1:1985, Acoustics, Statistical methods for determining and verifying stated noise emission values of machinery and equipment - Part 1: General considerations and definitions. International Organization for Standardization, Switzerland, 1985.

ISO 9613-1:1993 Acoustics, Attenuation of sound during propagation outdoors -- Part 1: Calculation of the absorption of sound by the atmosphere. International Organization for Standardization, Switzerland, 1993.

ISO 9613-2:1996 Acoustics, Attenuation of sound during propagation outdoors -- Part 2: General method of calculation

IEC 61400-11. Wind turbine generator systems – Part 11: Acoustic noise measurement techniques, edition 2.1 2006-11. International Electrotechnical Commission, Switzerland, 2006.

IEC 61400-11. Wind turbine generator systems – Part 11: Acoustic noise measurement techniques, edition 3.0 2012-11. International Electrotechnical Commission, Switzerland, 2012.

IEC TS 61400-14, Technical Specification, Wind turbines – Part 14: Declaration of apparent sound power level and tonality values. International Electrotechnical Commission, Switzerland, 2005

ISO 3744:2010. Acoustics - Determination of sound power levels and sound energy levels of noise sources using sound pressure - Engineering methods for an essentially free field over a reflecting plane. International Organization for Standardization, Switzerland, 2010.

Finnish Wind Atlas. Finnish Meteorological Institute, 2009. http://tuuliatlas.fmi.fi/en/

The Danish Ministry of the Environment. 2011. Statutory Order on Noise from Wind Turbines. Translation of Statutory Order no.1284 of 15 December 2011. 14 pages.

Zwicker, E., Fastl, H., Psychoacoustics. Facts and Models.2nd ed (Springer, Heidelberg, New York, 1999)

Moller, H. Pedersen, C.S., Pedersen, S. Staunstrup, J.K. Assessment of low frequency noise from wind turbines in Maastricht. Aalborg University, Denmark, 2011.