ON MEASURING AND DETERMINING WIND TURBINE NOISE EMISSIONS AT DISTANT SENSITIVE RECEPTOR LOCATIONS – A CHALLENGE

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Determining noise emissions attributable solely to wind turbine/s at potentially sensitive receptor locations far from the turbines is a technical challenge indeed. If the project is successfully designed acoustically, the wind turbine source is barely audible during the day or night with relatively moderate winds and not distinguishable at all during high winds. We must try to separate wind turbine emissions from the prevailing background environment and from sounds created by the same wind that drives the turbines. This paper suggests a methodology that measures surrounding turbine emissions simultaneously at the standard IEC-61400-11 distance to document background-free emissions for input into a relatively simple propagation model to calculate true turbine emissions at the distant receptor location of interest. An example is given from an actual site where turbine noise emissions could be accurately measured at the receptor location for comparison to model calculations.

INTRODUCTION

Measuring wind turbine noise emissions is unique, unlike any other power generation source because measurements must be made in the presence of wind. Other generation sources are customarily measured in quiescent or near quiescent meteorological conditions that of course are impossible for wind turbines. Measuring in windy conditions is problematical and introduces component sources that must be accounted for in the measured total sound pressure arriving at the microphone at the potentially sensitive location of interest. These are:

1. Wind induced pseudo microphone noise
2. Residual background sound from normal environmental sources
3. Background sound induced by wind (turbulence over the surface and grass, foliage and tree rustle)
4. Noise emissions from the wind turbine/s.

SOURCES OF NOISE AT FAR-OFF SENSITIVE RECEPTOR LOCATIONS

Figure 1 illustrates the measured flow induced pseudo noise using two diameter wind screens. A larger diameter is always better for any given porosity, and note there can be a 10+ dB improvement in measurement capability just by windscreen selection. This data is given in an experimental windscreen study at an aero-acoustic wind tunnel in Germany [1]. It should

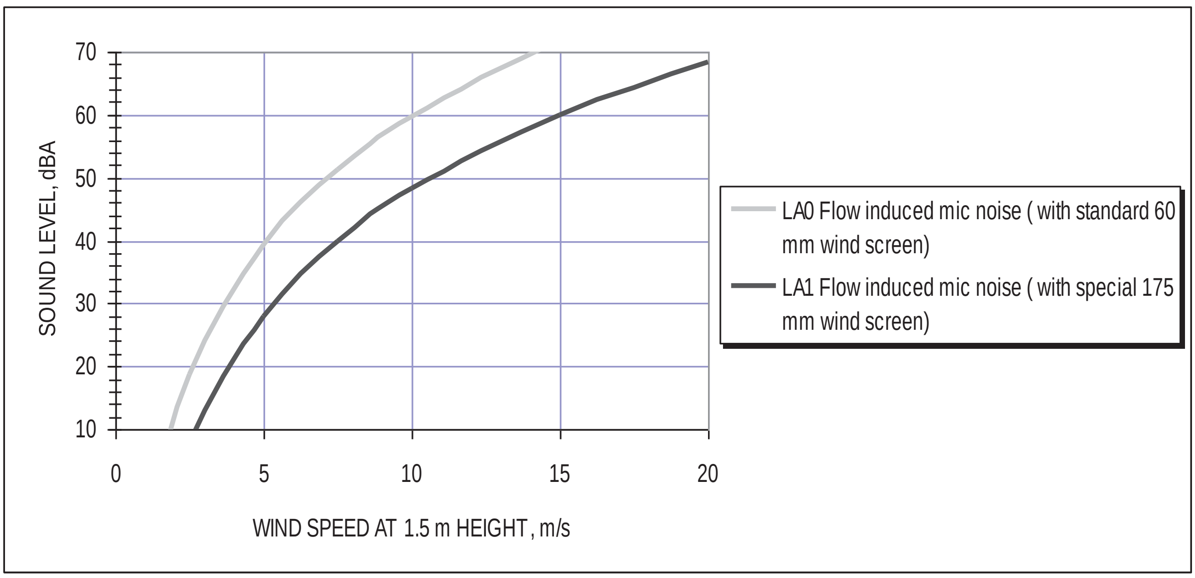

Figure 1. Measured pseudo microphone noise using two sizes of windscreens with identical porosity

be noted that controlled flow in a laboratory is less turbulent and steady than outdoor wind and actual pseudo noise may be higher than shown under field conditions.

Figure 2 shows the two components of background noise that makeup the total measurable level in a moderately windy environment. The short dashed line is the residual level usually from far-off unidentifiable traffic or industrial sources, while the long dash line is wind induced sounds. Wind source sound follows a 10^6 power slope as an aerodynamic source. The combination of the two components yields the background level as a function of wind speed.

Figure 3 is a typical shape of wind turbine noise emissions versus wind speed. When we combine all these sources in Figure 4, it is easy to see that the only measurable sound level at a point far from the turbines may not represent turbine emissions at all except in a small select range where the total can be corrected for background. We also show that a small standard windscreen can give a totally erroneous answer, and the larger size windscreen may still produce a component source in the measurement, particularly at higher speed.

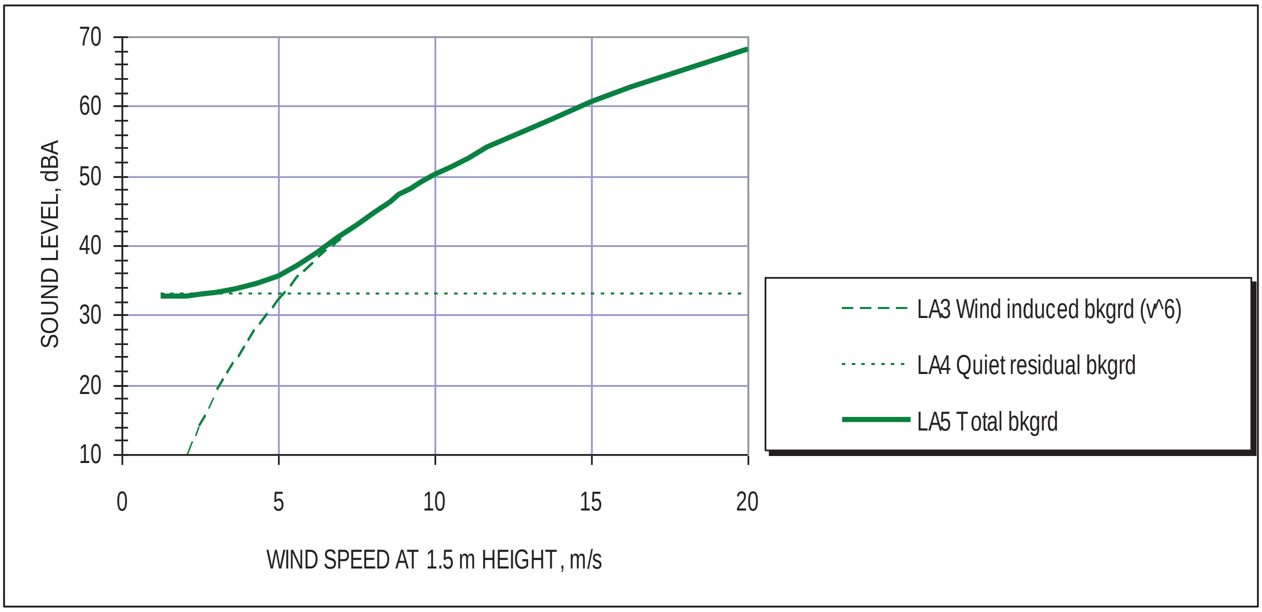

Figure 2. Residual background noise, wind induced sources and total background noise

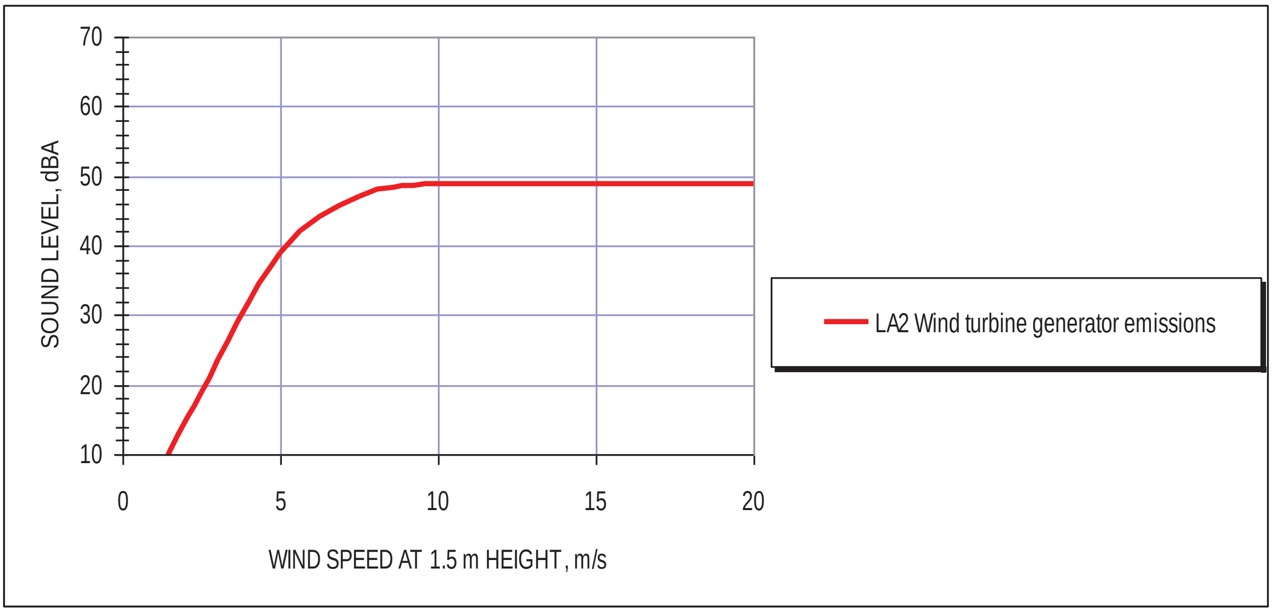

Figure 3. Wind turbine noise emissions as a function of wind speed

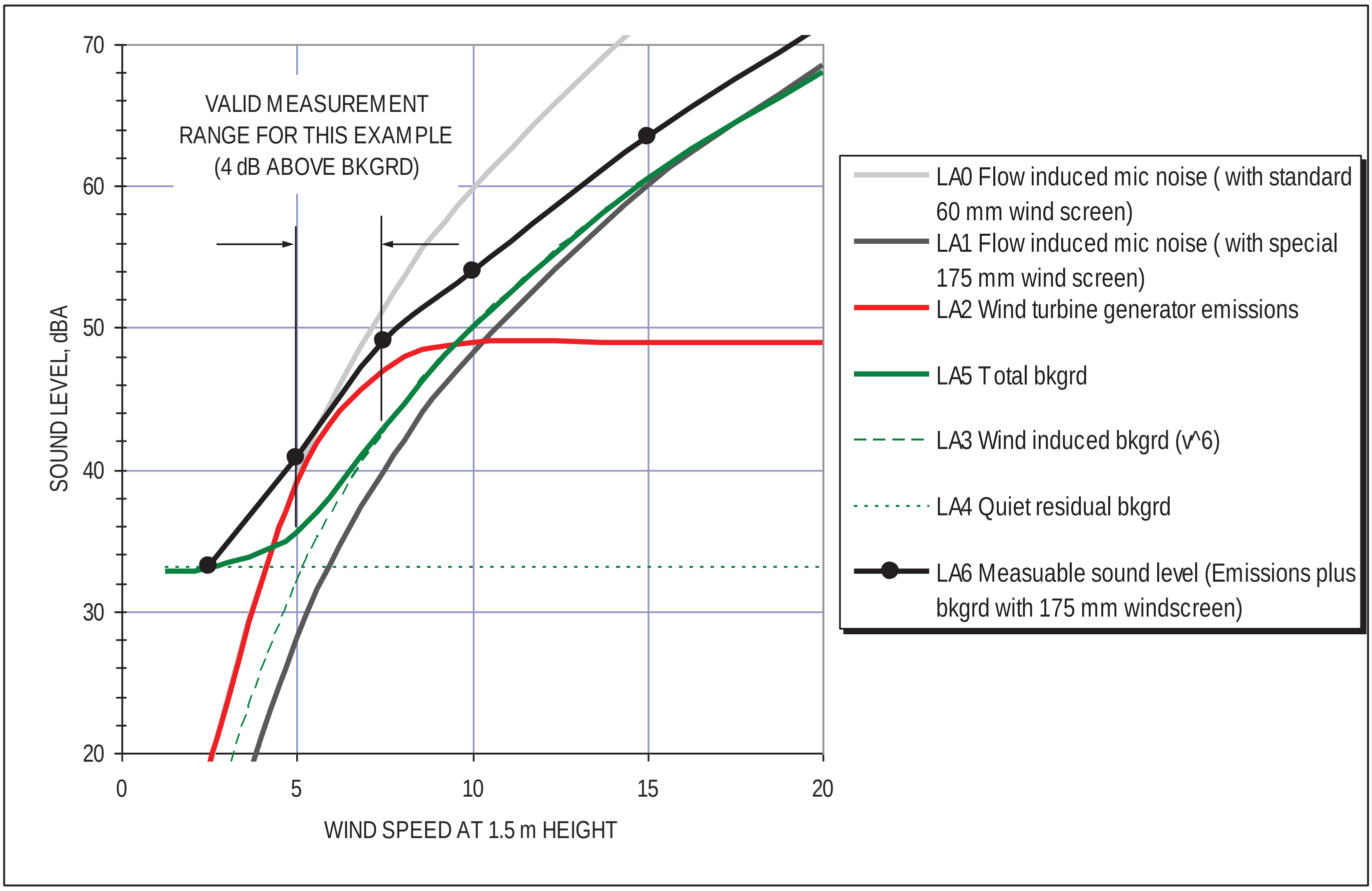

Figure 4. Combined sources of noise at a far-off sensitive receptor location

Background effects can be accounted for to a degree at observed and monitor testing with a cooperative owner by periodically turning off the closest and other surrounding turbines for say 10 or 20 minute periods and then restarting. For distances far from large facilities it may be necessary to shut down the entire facility. ON and OFF data can be compared and if the background sound is 3 or 4 dB or more below the total background may be subtracted. This works well at moderate speed but not so well at high speed and/or full load as there will be little change in level if the measurement is dominated by pseudo and wind induced background. Figure 4 also illustrates how easy it is to arrive at an accurate but incorrect answer. It should be made clear that Figures 1 to 4 are for illustrative value and do not represent data at any particular site.

PROPOSED MEASUREMENT METHODOLGY

Most of the measurement difficulties described above could be eliminated by selecting a measurement location closer to the turbine/s where one measures *only* turbine emissions, exclusive of background. This close-in alternate location is a time-honored successful technique and is suggested by South Australian EPA Noise Policy measurement standards for single sources under investigation. Here we develop and demonstrate the use of the close-in technique for multiple source wind turbine arrays.

A specific ideal location is prescribed in IEC 61400-11 [2] as one hub height plus one blade length away. At this location, there is no ground effect and background sound has little significance. Figure 5 shows a typical measurement with time at this location taken to show any background influence at shut off intervals and to keep the measurement location downwind. It is clear that only turbine emissions are being measured. The data spikes during shutdown are technician sounds aligning the instrumentation. The measurement for the proposed methodology could be on a reflective ground plane surface or on a tripod one to two meters above the surface as required.

We propose an in-situ test set-up as shown in Figure 6 for an array of multiple wind turbine sources. Measurements are carried out at the four closest turbines surrounding or closest to the location of interest. The measurements would be done simultaneously and note that they could be up, down or cross wind, accounting for any turbine noise directivity effects.

PROPOSED MODELLING TO DETERMINE WTG EMISSIONS

It remains to extrapolate the IEC distance results to the point of interest, L_{pi}. The data can be computed for each turbine by the following equation and then summed logarithmically to arrive at the wind turbine emissions exclusive of background and microphone effects:

$$L_{pi} = 20\log(d_{iec}/d_i) + A_a + A_g + C \tag{1}$$

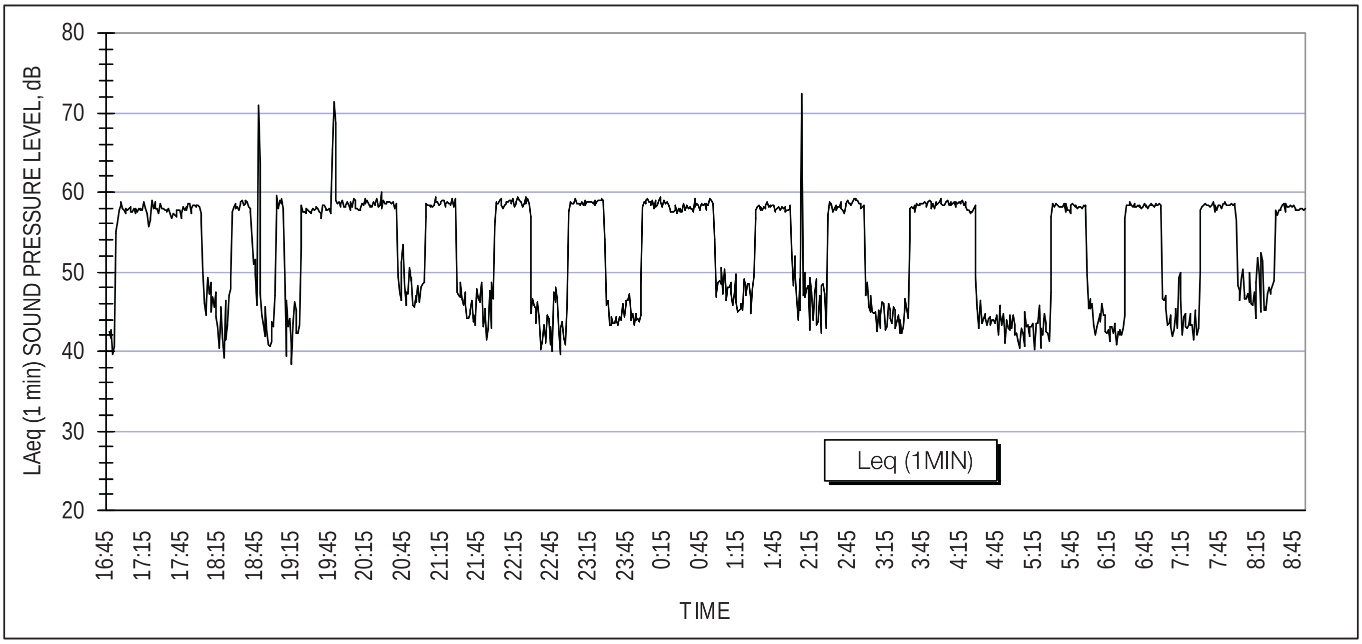

Figure 5. Typical raw data at the standard IEC 61400-11 test distance of hub height plus one blade length away

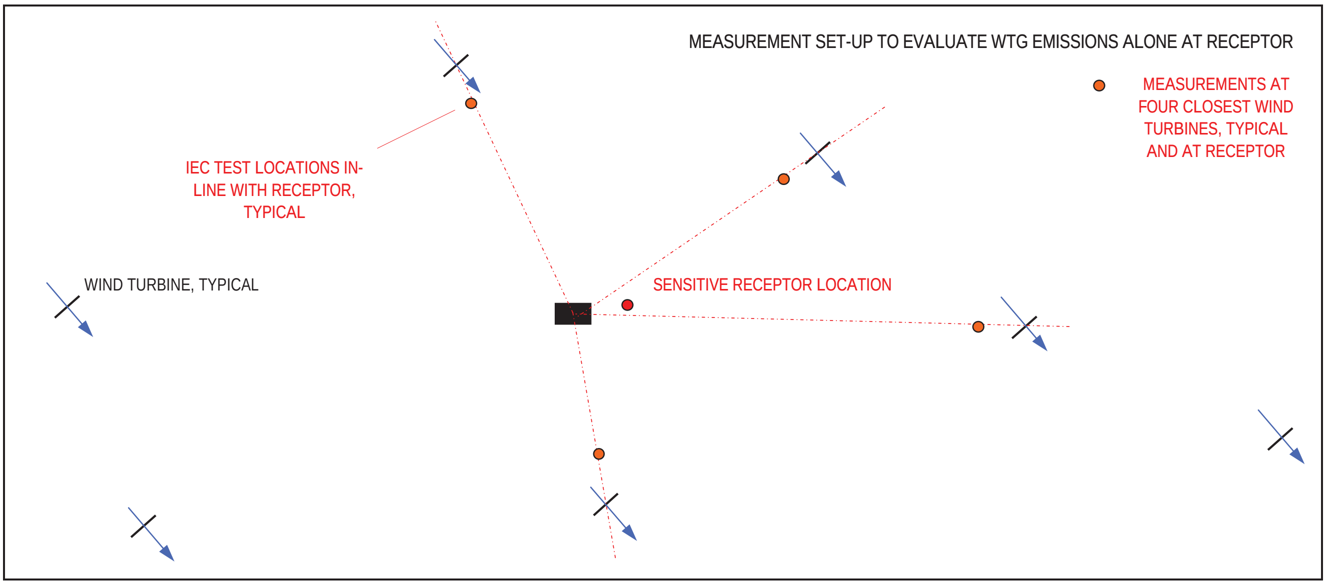

Figure 6. Proposed test set up for quantifying turbine emissions at a sensitive far-off receptor

The subscript i from 1 to 4 are for each turbine location. The IEC test distance is denoted d_{iec} and d_i is the distance from ith turbine to the sensitive location. A_a and A_g are for air absorption and ground effects both calculated by ISO-9613 part 2 algorithms. The quantity C is a correction factor to account for the balance of the wind farm turbines that may contribute to the measured level in addition to the four closest turbines. It can be shown that C would range from a small fraction to about 3 dBA depending on the layout of the wind project. In general, C would increase as one moves farther from the array. Figure 7 gives the computation results for correction C. The upper scenario is unlikely and perhaps unfortunate for the receptor and would certainly be the worst case. The lower scenario illustrates two extremes for a close and distant row of turbines.

Equation (1) comes from ISO 9613 and can be implemented in a simple A-weighted model or be done as a function of frequencies in octave bands. We suggest an octave band measurement and model for certification purposes and a simple A-wt model for information-only purposes. The modelling is very *minimal* and essentially we are simply *extrapolating* sound pressure from one distance to another in the same direction.

Experience shows that the quantity Ag is particularly important for wind turbines that have peak noise emissions at around 500 Hz. Ag depends almost exclusively on the ground surface *near* the point of interest measurement receiving location – see Figure 8. Using a ground absorption coefficient from 0.5 to 1 for "soft" surfaces has shown very good modelling results over long term sampling times.

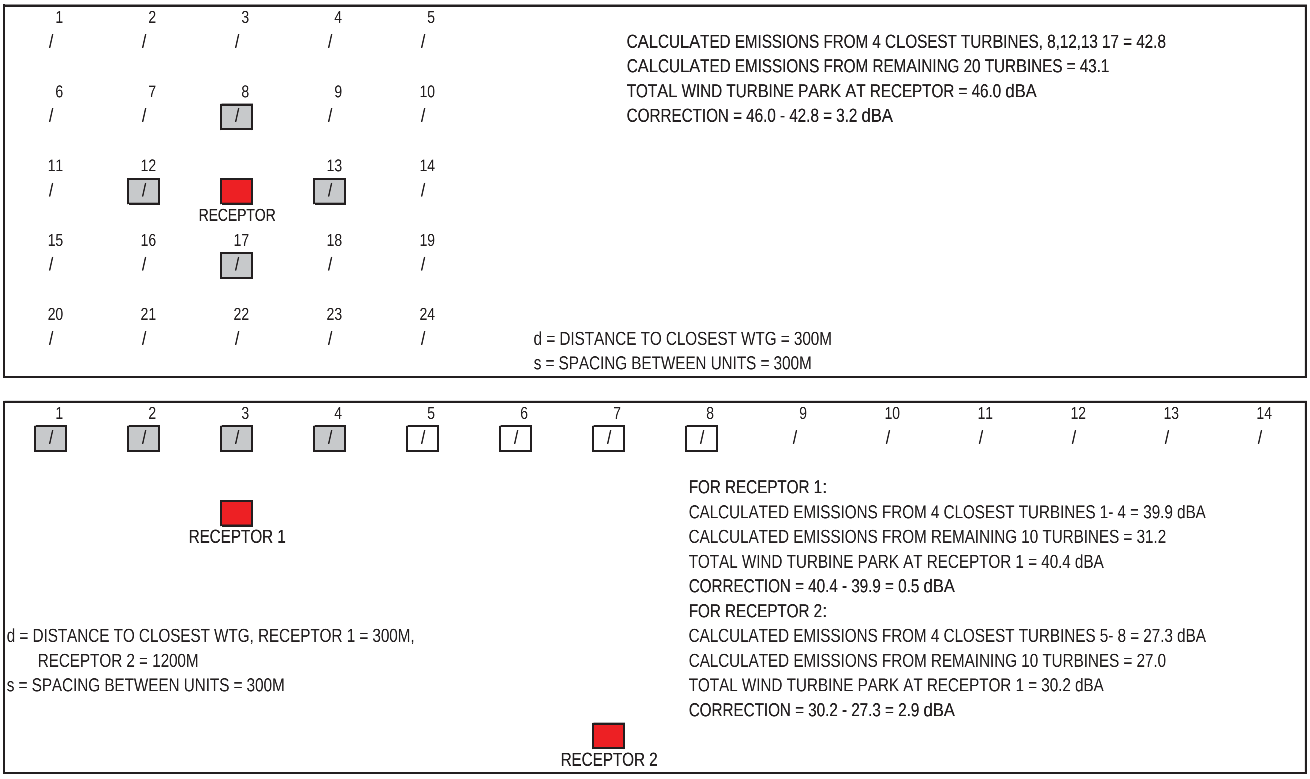

Figure 7. Computation results of correction C for use in equation (1)

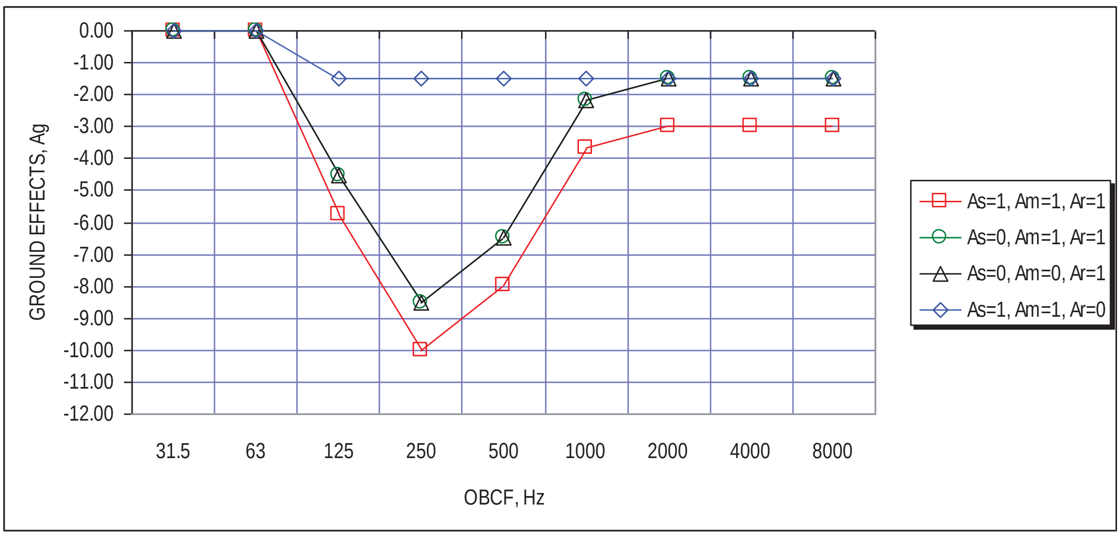

Figure 8. Computation of ISO 9613 ground effects where A is the chosen absorption coefficient for source, mid and receiving areas

A SAMPLE PROPAGATION MODEL

A sample simple A-weighted noise model is given in Table 1 for three residences relatively close to the turbines in accordance with ISO 9613 with the exception of the addition of correction C. Measurements at these locations were dominated by turbine noise so the site serves to compare the measured levels with the proposed methodology. The agreement is good and the emission levels deduced from IEC measurements appear a little conservative compared to actual measurements at the sensitive locations. A nice feature of this method is that the model can be extended (the blue text in Table 2) to see the benefit of shutting down just the closest turbine. In this example, the noise reduction ranged from 2.4 to 8.0 dBA due to the proximity of the surrounding turbines.

It should be noted that the data shown in the model for the IEC distance (58 dBA) comes from a single turbine test and not from the four closest turbines. This test methodology was developed well after this project was completed but this projects data is the best representative data available for the model. Results would be slightly lower if measured at each turbine since some would be upwind and cross wind rather than all downwind – a major advantage of the method. Nevertheless, the model is sufficiently accurate to show the potential value of the proposed method as intended.

CONCLUSIONS

A measurement and analysis methodology is proposed where noise emissions solely attributable to wind turbines can be measured accurately without background or pseudo noise concerns and then simply extrapolated to more distant sensitive receptor locations of interest. This avoids the difficulty of extracting the turbine emissions from total direct measurement at the same location of interest, a nearly impossible task. It is hoped the measurement and analysis method will be tried by other investigators towards the ultimate goal of standardisation.

REFERENCES

[1] G.F. Hessler, D.M. Hessler, P. Brandstätt and K. Bay, "Experimental study to determine wind-induced noise and windscreen attenuation effects on microphone response for environmental wind turbine and other applications", *Noise Control Engineering Journal* **56**(4), 300-309 (2008)

[2] International Electrotechnical Commission IEC 61400-11, *Wind turbine generator systems – Part 11: Acoustic noise measurement techniques*, Edition 2.1, 2006-11

Table 1. Sample A-weighted noise model

SIMPLE A-WTD MODEL BASED ON ISO 9613, PART 2 ALGORITHMS										
INPUTS IN RED				ISO 9613 PROPAGATION VALUES				CORR. C	CALC.	MEAS
Lp AT IEC POINT	HUB HT.	ROTOR DIA.	DISTANCE	DIST	AIR ABS	GROUND	MIC MOUNT	C	LA	LA
SITE M							Y/N			
58	80	80	252	-4.9	-.8	.0	-3.0	.5	49.8	
58	80	80	340	-7.5	-1.1	-.5	-3.0	.5	46.4	
58	80	80	377	-8.4	-1.2	-1.0	-3.0	.5	45.0	
58	80	80	402	-8.9	-1.3	-1.2	-3.0	.5	44.1	
							CALCULATED LEVEL		53.0	50-52
SITE N										
58	80	80	654	-13.1	-2.1	-2.6	-3.0	.7	37.8	
58	80	80	579	-12.1	-1.9	-2.3	-3.0	.7	39.4	
58	80	80	780	-14.7	-2.5	-3.0	-3.0	.7	35.5	
58	80	80	949	-16.4	-3.0	-3.3	-3.0	.7	33.0	
							CALCULATED LEVEL		43.1	42-44
SITE D										
58	80	80	302	-6.4	-1.0	.0	-3.0	1.8	49.4	
58	80	80	629	-12.8	-2.0	-2.5	-3.0	1.8	39.4	
58	80	80	767	-14.5	-2.5	-3.0	-3.0	1.8	36.9	
58	80	80	943	-16.3	-3.0	-3.3	-3.0	1.8	34.2	
							CALCULATED LEVEL		50.1	48-50

DIMENSIONS IN METERS MIC MOUNT: CORRECTION FOR MICROPHONE MOUNTED ON GROUND PLANE OR ON TRIPOD AT 1-2 M ABOVE GRADE

Table 2. Sample A-weighted noise model with abatement extension

SIMPLE A-WTD MODEL BASED ON ISO 9613, PART 2 ALGORITHMS											NOISE REDUCTION BY SHUTTING DOWN SINGLE CLOSEST WTG	
INPUTS IN RED				ISO 9613 PROPAGATION VALUES				CORR. C	CALC.	MEAS		
Lp AT IEC POINT	HUB HT.	ROTOR DIA.	DISTANCE	DIST	AIR ABS	GROUND	MIC MOUNT	C	LA	LA		
SITE M							Y/N					
58	80	80	252	-4.9	-.8	.0	-3.0	.5	49.8		.0	
58	80	80	340	-7.5	-1.1	-.5	-3.0	.5	46.4		46.4	
58	80	80	377	-8.4	-1.2	-1.0	-3.0	.5	45.0		45.0	
58	80	80	402	-8.9	-1.3	-1.2	-3.0	.5	44.1		44.1	
							CALCULATED LEVEL		53.0	50-52	50.1	2.9
SITE N												
58	80	80	654	-13.1	-2.1	-2.6	-3.0	.7	37.8		37.8	
58	80	80	579	-12.1	-1.9	-2.3	-3.0	.7	39.4		.0	
58	80	80	780	-14.7	-2.5	-3.0	-3.0	.7	35.5		35.5	
58	80	80	949	-16.4	-3.0	-3.3	-3.0	.7	33.0		33.0	
							CALCULATED LEVEL		43.1	42-44	40.7	2.4
SITE D												
58	80	80	302	-6.4	-1.0	.0	-3.0	1.8	49.4		.0	
58	80	80	629	-12.8	-2.0	-2.5	-3.0	1.8	39.4		39.4	
58	80	80	767	-14.5	-2.5	-3.0	-3.0	1.8	36.9		36.9	
58	80	80	943	-16.3	-3.0	-3.3	-3.0	1.8	34.2		34.2	
							CALCULATED LEVEL		50.1	48-50	42.1	8.0

DIMENSIONS IN METERS MIC MOUNT: CORRECTION FOR MICROPHONE MOUNTED ON GROUND PLANE OR ON TRIPOD AT 1-2 M ABOVE GRADE