Baseline Environmental Sound Levels for Wind Turbine Projects

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A comprehensive sound level survey is required to establish preconstruction baseline environmental sound levels for use as a design basis for any power plant project. Such data are essential to determine how much noise can be contributed by a new source before it becomes clearly audible and possibly disturbing to the surrounding community. Wind turbine projects are unique compared to more conventional power and industrial facilities. This is because the masking background sound level that is of interest is the level that is consistently present when a substantial wind is blowing, since that is the only time wind turbines produce significant noise. In essence, the background sound level must be determined as a function of wind speed.

For fossil fuel and nuclear power plants, the most important ambient noise metric is the residual sound level measured under "calm and still" conditions,[1] which are defined as essentially no wind and no audible sounds from grass, crops, or tree leaf rustle. Measuring low-level sound levels during windy conditions is problematic.

Wind turbines, which can now exceed 2 MW in electrical output capacity with rotor diameters that can span a football field, begin operation at a "cut-in" speed of approximately 3 to 4 m/s at a standardized[2] height of 10 m above ground level. A unique and positive feature of wind turbines is that they do not operate during calm, still, or tranquil conditions as are commonly found in rural environments where residual ambient levels can typically dip into the 25 to 30 dBA range. The turbines only produce noise under windy conditions when background sound levels are also naturally elevated.

Figure 1 shows the wind profiles above the ground surface at velocities of 4 and 8 m/s, measured at an IEC standardized height of 10 m. Most wind turbine models reach a maximum sound power output in the range of 7 to 8 m/s when the rotors reach maximum velocity. At higher wind speeds the blades do not turn any faster and noise production normally remains constant or even falls off slightly in some cases. A sampling of wind turbine sound power levels versus wind speed, as reported by the manufacturers, is plotted in Figure 2. The anomalous performance of Model B raises some doubt as to the validity of this particular manufacturer's data.

Because turbine noise levels vary with wind speed, it is necessary to measure ambient sound levels over a range of conditions from near calm to velocities of at least 8 m/s to establish a wind-sound level trend. Notice in Figure 1 that at a standard microphone height of only 1.5 meters, wind speeds would be approximately 2.8 and 5.6 m/s (or 6.5 to 13 mph) for the cut-in and maximum noise conditions. The two velocity values would be slightly higher at 3 m, a typical continuous monitor microphone height.

Measurement Techniques and Metrics

Octave-band spectrum measurements of the background sound level are necessary for wind turbine projects to not only collect sufficient data over the wind speed range of interest but also to have the ability to correct the spectra and resulting A-weighted sound level for spurious noises such as insects and self-induced wind noise over the microphone.

Insect noise during summertime surveys frequently causes a dramatic increase in recorded A-weighted sound levels relative to what might be measured in the wintertime – a situation

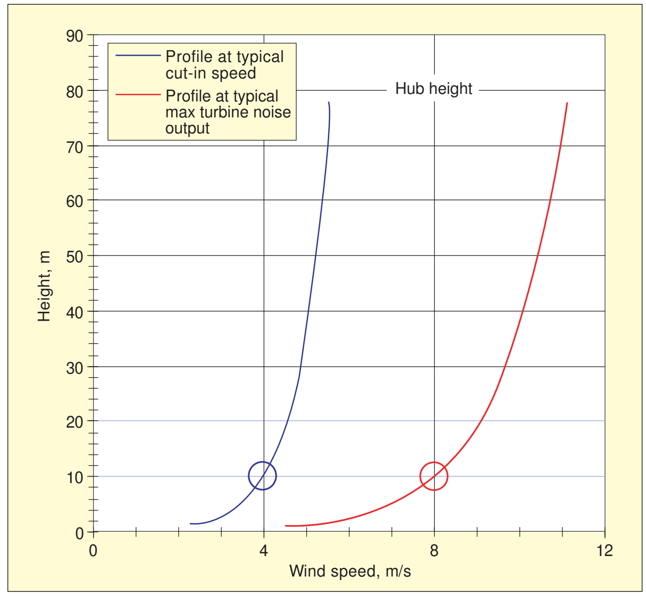

Figure 1. Wind speed profile at two key wind turbine operating points.

that might easily lead to a design background level that is not valid during quieter times. Because insect noise is concentrated in the highest frequency bands and obvious in a typical level vs. frequency plot, it can be mathematically removed and the modified octave bands can be re-summed to yield an estimated A-weighted sound level without this contamination.

Similarly, corrections are also possible for low-frequency microphone response errors by adjusting the relevant octave bands and recalculating more representative A- and C-weighted sound levels. As an example, Figure 3 shows that a significant error occurs when using a standard microphone windscreen in a steady 18-mph wind. The first three octave bands are all essentially false-signal turbulence noise. Discarding the 16- and 31.5-Hz octave band data and reducing the 63-Hz band to the lower wind noise limit 'corrects' or modifies the spectrum. The instrument supplier furnished the wind-noise values shown in red. The A- and C-weighted levels are calculated from the corrected spectrum and compared to the actual measured level to determine the error in overall levels. In this case, the error for the A-weighted level is significant at 1.2 dBA, and the C-weighted level error of 12 dBC demonstrates that calm conditions are essential when measuring C-weighted sound levels. The conclusion that can be drawn from this is that valid A-weighted sound levels can be measured with standard microphone windscreens up to a wind speed of about 15 mph (measured 2 m above ground level). Special techniques or a mathematical error correction should be considered for higher speeds.

Measurement Locations and Topography

Wind turbine projects can cover extremely large areas. A recent project encompassed 40 square miles with more than 100 turbines. In addition, topography can often play an important role. In many cases, the turbines are located along high, exposed ridgelines with houses in deep ravines or valleys immediately below. In other cases, projects are located on top of large swells or plateaus where the terrain between the turbines

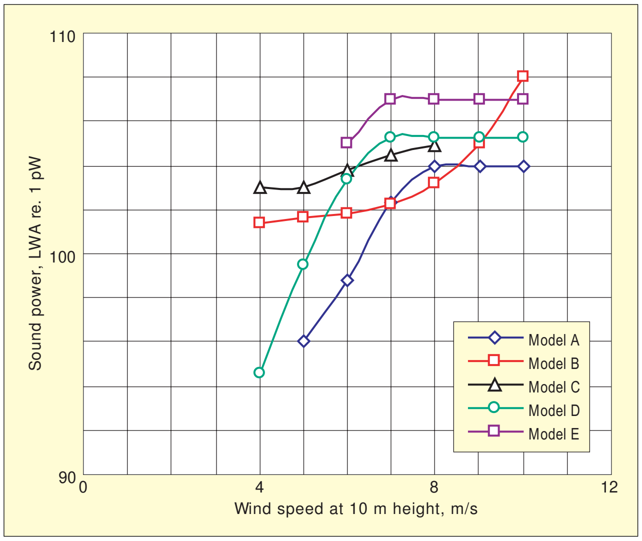

Figure 2. Sound power level as a function of wind velocity for four wind turbine models.

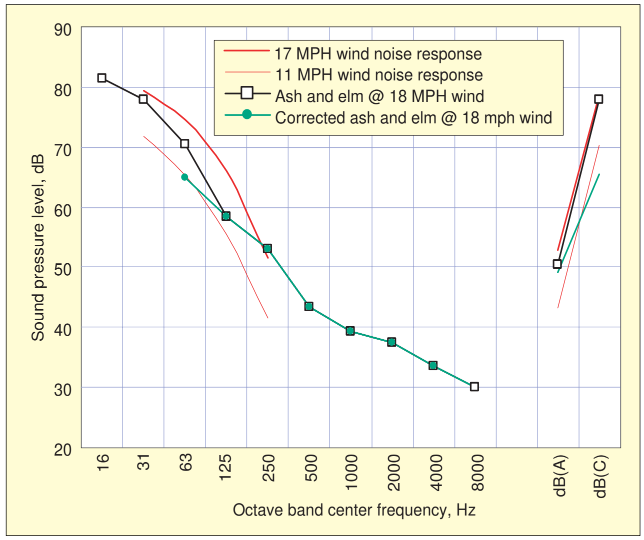

Figure 3. Measured spectrum (10 minutes, L90) in high wind measured 2 m above grade compared to "'corrected' spectrum.

and potential noise receptors is essentially flat.

When the terrain is largely flat and the houses and farms are spread out fairly evenly in a rural setting, measurements at four or five monitoring points distributed over the area often show that the sound level is surprisingly uniform, indicating that a macro-area ambient exists. Figure 4 is an example of such a site. This graphic clearly illustrates that similar sound levels occur at each location, some of which are more than 5 miles apart and that all the positions are similarly affected by and dominated by wind-induced sounds. This kind of result allows the background level to be estimated with reasonable confidence at any specific location on the site under virtually any wind condition.

For other projects situated in complex terrain, there is often considerably less correlation between wind speed and ambient levels due to the 'roughness' of the topography as opposed to flat open terrain. Sound levels are often relatively low in sheltered valleys and higher in more exposed parts of the site. For these projects, it is necessary to develop typical ambient levels to characterize each type of environment where potentially sensitive receptors are located. This usually means developing one background design level for those residences in lower, more protected locations and another design level for homes on the ridge tops.

Data Collection and Duration of Measurements

When project schedules are extremely aggressive and the noise assessment must be completed quickly, manual spot measurements (as opposed to long-term monitoring) can suffice if enough locations are selected and each is visited often enough to collect enough samples. However, a sufficient variety of wind conditions must occur within a short time frame to make this approach work.

The sound level/wind speed results obtained during such a manual survey are shown in Figure 5. The upward trend of the residual level versus wind speed is clear with only 25 samples. This site was flat farmland without any major highway noise sources nearby.

Figure 6 plots approximately 400, 10-minute sound level results compared to the 25 manual readings presented above. The corresponding wind speed for the same three-day period was collected at a met tower about 1000 feet away. The effect

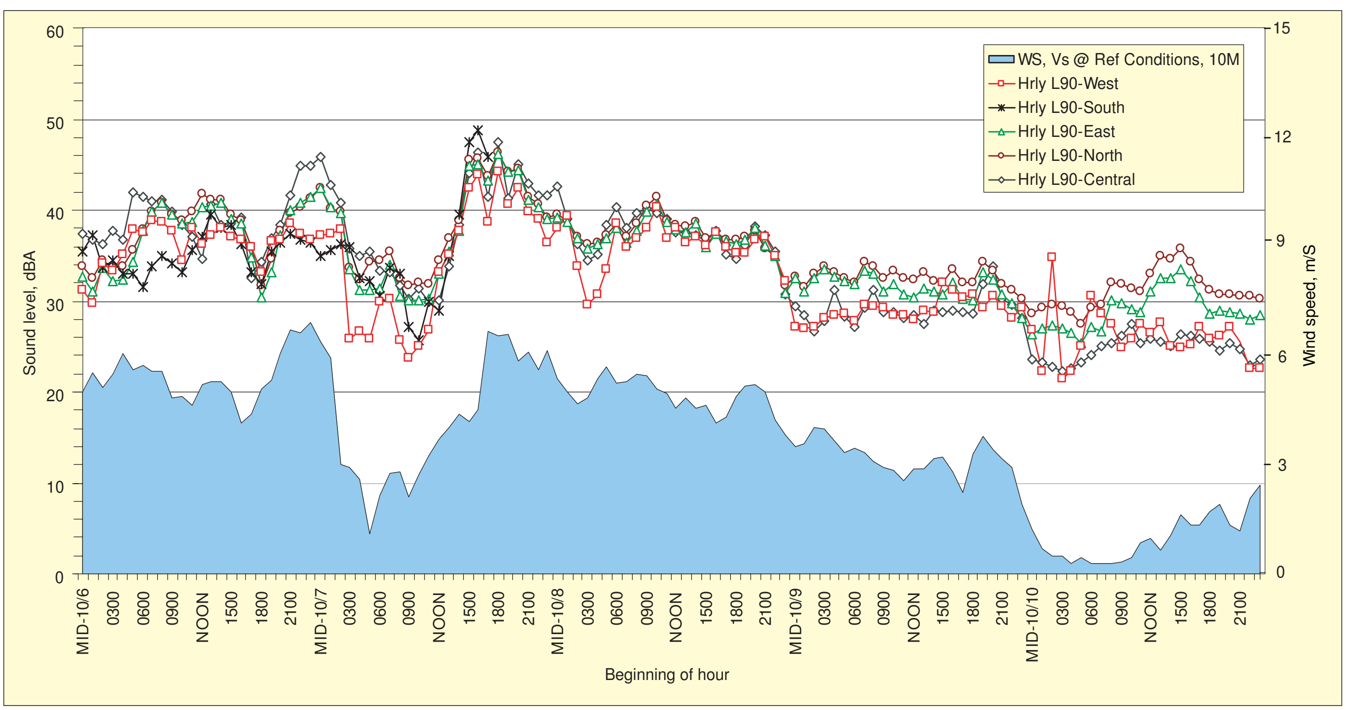

Figure 4. Measured residual (L90) sound levels over a 40-square-mile project area using five continuous monitors.

		Loc. 1	Loc. 2	Loc. 3	Loc. 4	Loc. 5
Time of Day	Wind Condition	WS, mph / L90, dBA				
Evening, 1/17/06	High west wind	7 / 35	9 / 45	6 / 41	12 / 44	9 / 42
Night, 1/17/06	High west wind	9 / 41	8 / 39	3 / 32	7 / 37	10 / 42
Morning, 1/18/06	High west wind	11 / 46	12 / 47	6 / 45	14 / 47	13 / 52
Noon, 1/18/06	High west wind	17 / 51	17 / 51	10 / 48	18 / 50	18 / 49
Noon, 1/19/06	Mild west wind	8 / 35	8 / 41	5 / 36	7 / 34	7 / 34

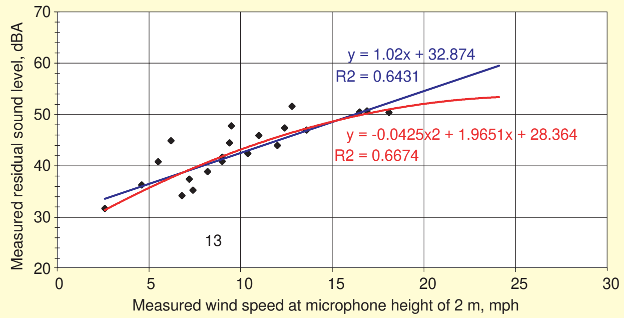

Figure 5. Table and graph of manual survey sound levels vs. wind speed.

of wind on the measured sound level is shown clearly in the plot. The regression of these data is shown in the figure.

The data collapse as the wind speed increases, and the scatter is greatest during calm to low-speed wind conditions. If the data below 4 m/s wind speed were ignored, the R-squared value would improve to 0.85 versus 0.65. Of course there are many other factors influencing the ambient level during calm conditions, such as time of day or night, far-off traffic patterns, long-distance sound propagation,, proximity of vegetation, nature sounds, and others.

Continuous monitoring in octave bands is the preferred method for collecting enough samples for analyses. A 12 V auto battery will drive a typical sound level meter for about a month even in the coldest climate. A packaged sound monitoring system on wheels is shown in **Figure 7**. The case houses a Norsonics 118, 1/3 octave band analyzer and a Rion NL 31 sound level meter with a sound recording card set to activate at a threshold level of around 55 dBA. The sound card feature allows a later playback and identification of any relatively loud noise events, such as thunderstorms, heavy rain, farm equipment, etc. The two meters complement each other and provide a backup to ensure collection of dependable A-weighted levels.

Figure 7. Portable sound monitoring system containing a standard Type 1 sound level meter and additional meter with digital audio recording capability.

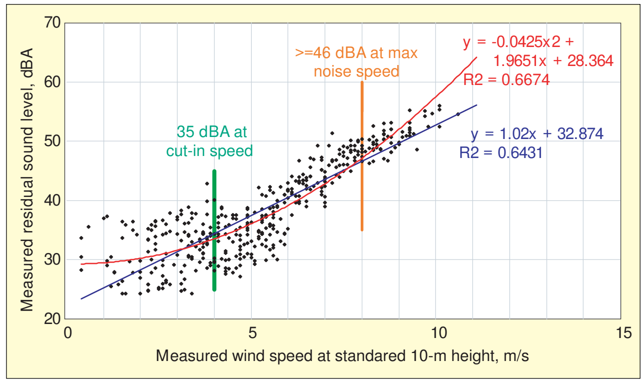

Figure 6. Plot of measured sound level and wind speed over same three-day sampling period as Figure 5, showing manual results.

Seasonal Considerations

The major environmental sounds produced by wind are grass, crop, and tree-leaf rustle. It is not uncommon to observe an increase of 8 to 10 dBA in ambient sound level from leafed out trees as a breeze or wind gust occurs. Minimum ambient levels can be expected during winter when the trees are bare, crops have been harvested, and there is no insect noise. Therefore, if background measurements are collected during winter, one can expect the results to represent the minimum residual ambient level for the entire year.

The results of four wintertime surveys in three states are plotted in **Figure 8**. All of the sites were relatively flat, and three of the four could mainly be characterized as farmland. The increase in residual ambient level with wind is approximately 2 dBA/meter/sec. There is a built-in conservative factor when using wintertime ambient results as a year-round design basis, since summertime levels are likely to be higher. Nevertheless, one could use the average result for planning purposes.

Summary and Conclusions

A noise impact assessment for any proposed wind turbine project requires a survey of existing environmental sound levels at the site to establish what minimum level of natural masking noise is consistently present to obscure noise from the project. Adverse impacts occur when the new noise from a project significantly exceeds the background level at sensitive receptors and becomes clearly audible.

Determining what background level to use as a design basis is strongly tied to wind speed, since wind turbines only generate noise under windy conditions. Because background levels also increase during windy conditions, a fairly extensive sound level survey is usually necessary so that measured levels can be correlated to a range of wind speeds. In general, a regression plot of sound level vs. wind speed needs to be developed from the survey data so that, among other things, the

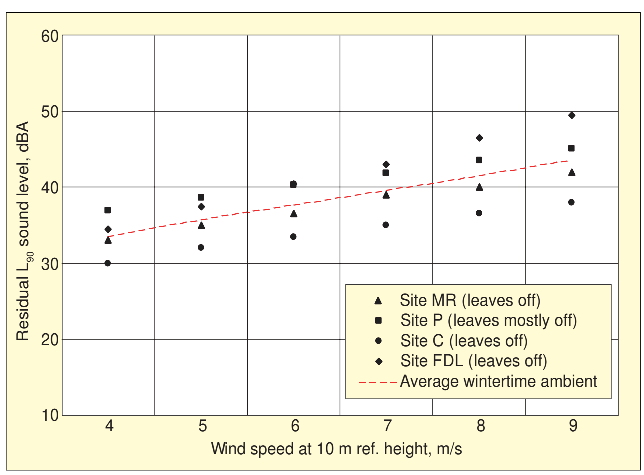

Figure 8. Measured residual ambient sound level versus wind speed for wintertime conditions at four sites in three states.

background level at about 8 m/s can be identified. Most wind turbines in the 1.5- to 2.0-MW range produce the maximum amount of the noise at this speed. At higher wind speeds, the turbine rotor speed does not increase, so noise levels remain largely constant while background levels continue to increase.

Experience in conducting a number of baseline wind project surveys indicates that a macro-area ambient is often present in rural settings removed from major highways and other significant sources of man-made noise. This allows the sound level at any point of interest within the site area to be estimated with reasonable accuracy and also allows potential impacts to be determined on a site-wide basis.

To exclude certain contaminating noise and to correct measured sound levels for self-induced wind noise, it is necessary to record not only the A-weighted sound level but also the octave-band frequency content of the background sound level. For example, this approach allows the mathematical subtraction of high-frequency insect noise from summertime survey results yielding a modified A-weighted sound level that can be used as a year-round design basis. Without this adjustment, one might easily overestimate the long-term background level, particularly the nighttime level, that is present at the site. It is the lowest sound level that is consistently present and available to mask project noise that is sought in every baseline ambient sound survey.

References

1. Hessler, G. F., "Controlling Noise Impact in the Community from Power Plant Operations-Recommendations for Ambient Measurements," *Noise Control Engineering Journal*, Volume 48, Number 5, September - October 2000.
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