WTN 2011

Fourth International Meeting on Wind Turbine Noise

Rome Italy 12-14 April 2011

Accounting for Background Noise when Measuring Operational Sound Levels from Wind Turbine Projects

David Hessler, P.E., INCE

Hessler Associates, Inc.

3862 Clifton Manor Place

Haymarket, VA 20169 USA

david@hesslerassociates.com

Abstract

Sound levels from operational wind turbine projects are often relatively low in overall magnitude at the nearest potentially sensitive receptors because they are always at least several hundred meters away. Long propagation distances can lead to a situation where the project sound level is generally comparable to the natural background sound level. Consequently, the total measured sound level at a distant point of interest rarely quantifies the actual project-only sound level but instead reflects the sum of both project noise and a typically significant background noise component. If the background contribution is not factored out in some way, the result will erroneously overestimate the project sound level at that position. Such an error is undesirable in all circumstances but is particularly unwelcome when the purpose of the test is to verify compliance with regulatory limits or planning consent conditions. In the special case of wind turbines, the sound generated by a project is highly variable with time and directly dependent on the very specific wind and atmospheric conditions occurring at a particular moment, meaning that a generic background sound level measured under generally similar conditions at some other time can't really be relied upon to represent the background level that would have otherwise existed during a measurement of operational sound. Even if the wind speed were about the same, the wind direction, shear gradient, degree of turbulence, thermal gradient, humidity, cloud cover, foliage, etc., all of which have a bearing on wind turbine sound, may all have been different. What is needed to derive the project-only sound level is a measurement of the background sound level at the same time and under the same conditions as the operational sound level is measured so that this level can be subtracted from the total to yield the project sound level. This is sometimes achieved by temporarily shutting down the turbine under test, if not the entire project, but this approach is often impractical for a variety of reasons. This paper suggests and discusses an alternative approach using off-site "proxy" sound monitors to create a time history of the likely on-site background

levels allowing the project-only sound level to be reasonably estimated at any time during a long-term measurement survey of operational sound levels.

Introduction

Sound levels from operational wind turbine projects are often relatively low in overall magnitude at the nearest potentially sensitive receptors because they are always at least several hundred meters away, if only due to set back requirements, and frequently much further away. Long propagation distances can lead to a situation where the project sound level is generally comparable to the natural background sound level, particularly under the windy conditions necessary for the project to operate. Consequently, the total measured sound level at a point of interest, such as a residence hundreds of meters from the nearest turbine, rarely quantifies the actual project-only sound level but instead reflects the sum of both project noise and a typically significant background noise component. If the background contribution is blithely assumed to be negligible and not factored out in some way, the result will erroneously overestimate the project sound level at that position. Such an error is undesirable in all circumstances but is particularly unwelcome when the purpose of the test is to verify compliance with regulatory limits or planning consent conditions.

In the special case of wind turbines, the sound generated by a project is highly variable with time and directly dependent on the very specific wind and atmospheric conditions occurring at a particular moment, meaning that a generic background sound level measured under generally similar conditions at some other time can't really be relied upon to represent the background level that would have otherwise existed during a measurement of operational sound. Even if the wind speed were about the same, the wind direction, shear gradient, degree of turbulence, thermal gradient, humidity, cloud cover, foliage, etc., all of which have a bearing on wind turbine sound, may all have been different. What is needed to derive the project-only sound level is a measurement of the background sound level at the same time and under the same conditions as the operational sound level is measured so that this level can be subtracted from the total to yield the project sound level. This is sometimes achieved by temporarily shutting down the turbine under test, if not the entire project, but this approach is often impractical for a variety of reasons. This paper suggests and discusses an alternative approach using off-site "proxy" sound monitors to create a time history of the likely on-site background levels allowing the project-only sound level to be reasonably estimated at any time during a long-term measurement survey of operational sound levels. Surveys of two to four weeks in duration are typically required to adequately capture turbine sound levels over a full range of wind and atmospheric conditions.

Typical Background Levels

In the rural or semi-rural environments in which wind projects are typically located the background sound level may subjectively appear to be negligible or even zero to a casual observer but that is almost never actually the case. The plot below (Figure 1) shows the results of a very typical pre-construction background survey for a proposed wind project where $L_{A90(10\ min)}$ sound levels were measured over a 14 day

period at 6 locations representative of the nearest potentially sensitive receptors. Even during periods of essentially calm winds the sound level is not zero but rather in the 25 to 30 dBA range and, more importantly, when the wind speed increases the sound level can easily increase to more than 50 dBA.

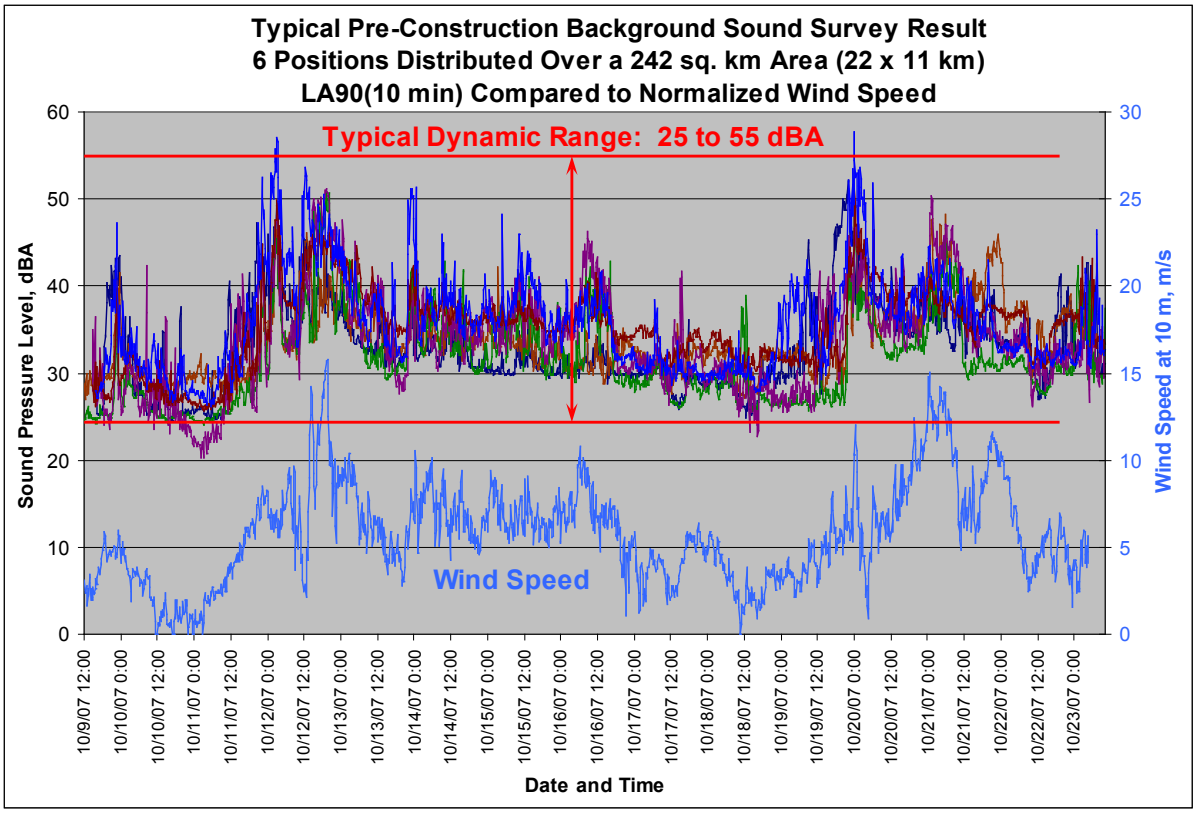

Figure 1

In general, it is common for background levels, even the near-minimum L_{A90} statistical, at typical wind project sites to range from 25 to 55 dBA – without any wind turbines present. Since it is not unusual for project-only sound levels to be in the 35 to 45 dBA range at residences during moderately windy conditions, one can clearly see that background noise must be accounted for in some way when attempting to accurately quantify the project-only sound level. If, for instance, the allowable limit for the project associated with Figure 1 were 40 dBA at non-participating residences, the background sound level would need to be 30 dBA or less in all winds higher than about 5 m/s to be rightfully neglected. Obviously, an assumption at this site during an operational sound test that background noise can be ignored would undoubtedly lead to the unfavorable conclusion that project noise exceeds 40 dBA much or most of time while the truth of the matter could well be that project noise was actually insignificant or even undetectable. Without any quantitative analysis of the background level one would essentially be left without any definitive conclusion either way except for the appearance that project noise is higher than it most likely is.

One current approach to defining the background level is to take spot measurements during calm conditions while the project is idle, or even before it is built, and use this result as a "conservative" estimate of the background level while the project is operating. From Figure 1 it can be seen that this tactic would likely lead to a working value somewhere between 20 and 30 dBA, which, besides being fallacious, would have the same effect as neglecting the background level altogether as just discussed. The sound level measured at night during a dead calm, for instance, generally has no relevance to the background levels that typically exists during normal operating conditions. The justification that this approach accounts for all conceivable wind shear and atmospheric stability conditions goes well beyond being reasonably conservative.

One final point about Figure 1 is that the 6 monitoring positions for this particular survey were distributed over an unusually large 242 sq. km area in which some monitors were over 22 km (14 mi) apart. What is remarkable about this is that the levels at all the positions are as similar as they are. They all follow the same wind-driven temporal trends and no one position is consistently higher or lower than the others; rather they intertwine together in such a way that the arithmetic average can reasonably be taken to be representative of the sound level at virtually any location within the entire site area. This is a common and by now expected finding at all rural sites and is germane to the discussion of proxy measurement positions below.

Proxy Background Measurements

The tendency, at least in fairly homogenous rural settings, for sound levels measured over a wide area to be similar can be applied to the problem of quantifying the background sound level a specific time that might otherwise have existed at a given measurement position close to or within a wind turbine project area if the turbines weren't present.

The general idea is to set up continuously recording monitors at several positions well outside of the project area - as a supplement to the on-site positions - that are far enough away from any turbines that project noise is undetectable but not so far that the measured levels are unrepresentative of the site area itself. If the results from these off-site locations surrounding the project area turn out to be similar, the arithmetic average can be considered a reasonable estimate of the background sound level that would have existed within the site area (in-between the background positions) over the survey period. This "proxy" background level can then be subtracted from the total sound level recorded at the same time at the on-site positions to derive the project-only sound level at each position.

Of course, comparable statistical measures must be used in this calculation for both the on-site and off-site levels. It has generally been found that the $L_{A90(10\ min)}$ measure leads to give the clearest result since sporadic noises, which are usually unrelated to the project, are essentially filtered out. The average, or L_{eq}, on the other hand, is usually so dominated by contaminating noise events that it is not very meaningful. In fact, both the on-site and off-site L_{eq} levels are often similar, falsely

suggesting that project noise is undetectable or insignificant - when that is frequently not the case.

While the exact background sound level at each on-site position at a specific moment is unknowable in the presence of operational noise, this approach of estimating the background from simultaneous measurements made just out of earshot of the project during identical atmospheric conditions is considered vastly superior to either assuming the background is negligible or estimating it from measurements taken at another time under necessarily different wind and weather conditions.

Selecting Off-Site Measurement Positions

As mentioned above, proxy background measurement locations should be far enough away that project noise is negligible and yet close enough that they are reasonably representative of the site area. It is generally sufficient to establish off-site positions at least 2.5 to 4 km (1.5 to 2.5 mi) from the nearest turbine associated with the project being tested or any other turbine that might be part of an adjoining project. At this distance, wind turbine noise is usually inaudible and/or almost certainly negligible in magnitude.

For projects in rural areas where the site surroundings are similar in topography and general character to the site itself, the ideal off-site monitoring locations would be diametrically opposed in the four cardinal directions. A typical example of a project in homogenous, open farm country is illustrated in Figure 2. Note that the southern position is moved to the west to avoid unrepresentative noise from an interstate highway and a fairly large town to the south of the project area.

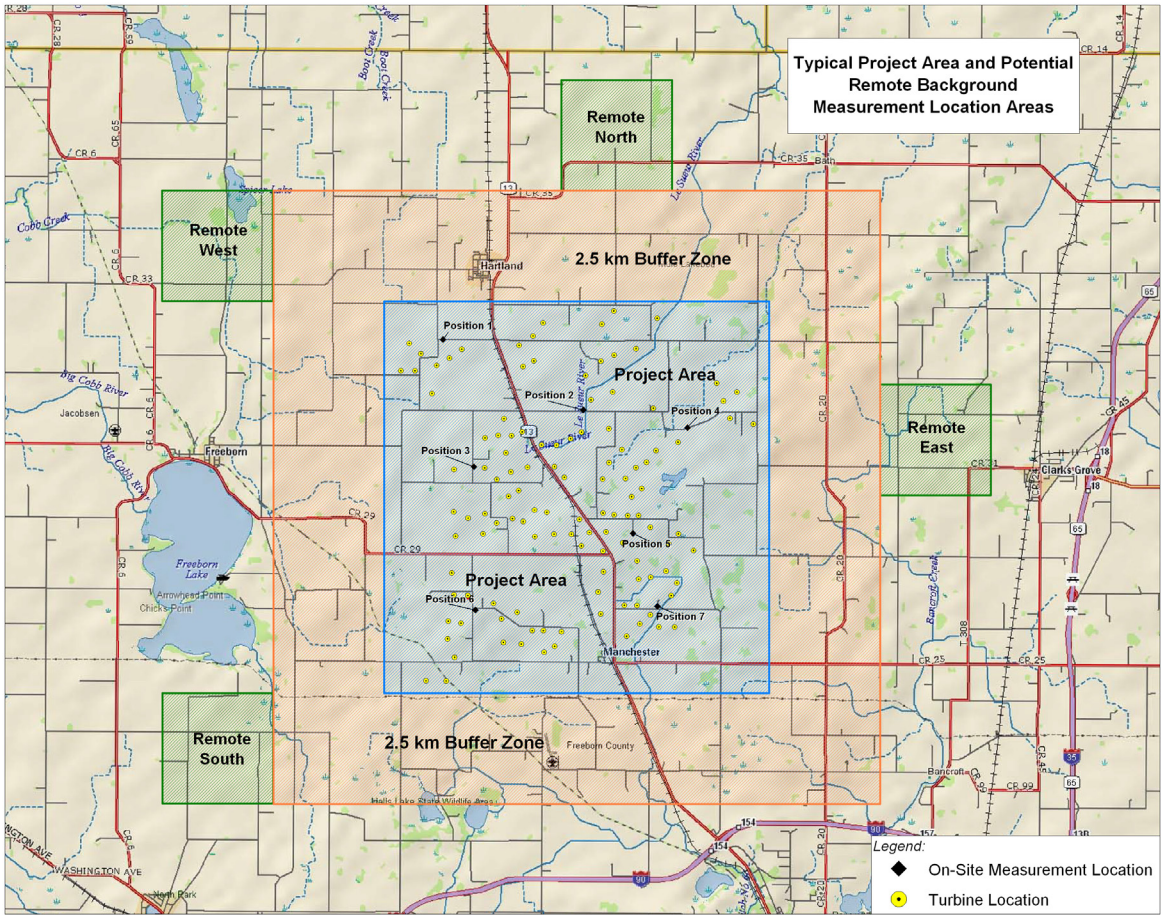

Figure 2

The positions themselves should be similar in character and setting to the positions of primary interest on or within the site area, which are generally residences. For example, if the key receptor points are on high and exposed hilltops then the background positions should be on similar hilltops. If the residences are sheltered in valleys then the background positions should mirror this setting, including such things as the proximity to wooded areas and the typical setback distances from residences to roads. It is often necessary to establish off-site monitoring positions that are in varied settings representative of all those encountered at the on-site measurement locations. Many sites have houses in high and exposed settings and in protected valleys each requiring representative proxy measurement positions. There may be more than one background level if the background levels in the sheltered locations, for instance, are consistently quieter than the levels measured in other settings. Experience suggests, however, that all the off-site monitors will have similar, intertwining levels even when a variety of off-site settings were deliberately chosen in an effort to represent each major type of on-site setting.

Care should be taken to avoid monitoring positions, both on and off the site, that are anywhere near audible flowing or potentially flowing water, such as streams, small rivers, and drainage ditches, since there is a strong tendency for water flow noise to

either obscure project noise or create an artificial noise floor. For simple reasons of topography streams are often found near homes that are located in ravines below ridge crest turbines making for a difficult situation. When a key receptor point, such as the closest residence to project turbines, is located near flowing water it is best to find another measurement point to the extent practicable with similar exposure to project noise but away from the flow noise, since this sound source may not always be present and will almost certainly vary substantially in magnitude with the flow rate in the stream, creek or ditch.

Fortunately, for the purpose of estimating simultaneous background sound levels, most wind projects are located in rural areas but, of course, not all of them are and other situations exist. In urban settings or near major highways the background sound is no less important, in fact more so, but its dependence on wind and atmospheric conditions is greatly diminished, if not relegated into complete insignificance. In such cases, the proxy background technique is still theoretically viable although the selection of background positions that are representative of receptors potentially affected by project noise becomes highly specific to the circumstances at each receptor. In the case of a highway, for instance, one might try to find a background position that is the same distance from the roadway as the actual point of interest and similar in all other ways but far enough from any turbines that they are undetectable. In this kind of a complicated situation where the background level is more dependent on man made noise than natural, wind-induced sounds it may be necessary to perform a pre-construction survey at the key receptors near turbines and at a number of candidate background positions to evaluate the validity of the proxy locations (i.e. their degree of correlation to the actual background sound levels on the site) before the project turbines become operational.

Similarly, the general validity of the approach can be evaluated for any project by temporarily shutting down the project when the wind speed is the critical 5 to 7 m/s range and comparing the off-site background levels to the actual background levels at the on-site positions during the shutdown.

Correcting On-Site Measurements for Background Noise

Once a site-wide or setting specific design L_{A90} background sound level has been developed from the data collected at the off-site proxy positions it can then be subtracted in the usual logarithmic manner from the L_{A90} levels measured at each of the on-site positions to deduce the project-only sound level. However, this correction process is only relevant to samples recorded while the turbines were actually in operation and not necessarily to all samples; consequently, the data must be sifted to ignore all periods of calm winds. This can be accomplished by dealing only with data sets collected above the effective cut-in wind speed for the turbine model in question (bearing in mind whether that wind speed is measured at 10 m or hub height) or, more preferably, by comparing the measured data to a time history of project electrical output obtained from the SCADA, or project control system. For this latter option it is best to compare the operational output of the 2 or 3 units

closest to each on-site measurement position rather than the total project output because this not only accurately defines the on and off times at each monitoring station but also may reveal, the fairly common occurrence, that certain units were temporarily down for maintenance or due to some unexpected malfunction. The relevance of this, of course, is that the measurements of project noise during this period would not have captured the maximum possible sound level.

Because the proxy background level is, for practical reasons, an inexact estimation of the site-wide background level, there will usually be instances when the background level exceeds the total measured level at certain on-site positions. Under this circumstance, and when the background level is below but within 3 dB of the total level, the project-only sound level would normally be considered indeterminate. In such cases, a decision has to be taken whether to simply discard these samples or take a slightly less cautious tack and assume the background level is dominant and that turbine noise must be at least 10 dB below the measured level – and therefore subtract 10 dB from the total measured level to estimate the project-only sound level. Both approaches have their merits with the second option leading, probably not unfairly, to a slightly lower result. A third possible path, that of taking no correction under these circumstances and assuming the total level is due entirely to turbine noise, probably is unfair and is not recommended.

While the calculation of the project-only sound level is mathematically possible when the background level is below but within 3 dB of the total level, doing so tends to create spurious mathematical artifacts where the project level can be estimated at unrealistically low and obviously incorrect sound levels. Since most standards, such as ISO 3746 [1], essentially disallow this calculation it seems best to follow that policy here as well. IEC 61400-11 [2] takes the somewhat unusual hybrid approach of allowing the calculation only where the difference between the total and background levels is 6 dB or more and suggests using a constant of 1.3 dB as a universal correction for differences of between 6 and 3 dB.

Example

Figure 3 below is a plot of the sound levels measured at three proxy background locations surrounding from a site in the Eastern United States where the landscape is rural and generally homogenous in nature within the project area and for some distance beyond it in terms of topography (rolling hills), vegetation (a mix of farm fields and wooded areas) and population density (farms and residences scattered more or less uniformly over the site area). The 80 or so 1.5 MW turbines are spread throughout a roughly 5200 ha (20 sq. mi) project area on numerous parcels of private land and thoroughly intermixed with the residences in the area. Proxy background measurement positions were set up about 3 km beyond the perimeter of the turbine array to the northwest, east and south of the project (a neighboring wind project to the west prevented measurements in that direction) at locations that were similar in character to the various settings near on-site residences; i.e. one was on an open and exposed hilltop, another was at the edge of a field with nearby trees and a third was essentially in a forested area. The expectation was that there might

be a consistent difference between these different positions – with the sheltered forest location being quieter than the windy hilltop, for instance – in which case background corrections for a particular setting would be applied to on-site measurements at positions with comparable settings. However, as can be seen from the figure, the levels at all three locations, each many kilometers from the others, were largely the same at any given time and, perhaps more significantly, no one position is consistently higher or lower than the others. Consequently, the arithmetic average of all three, with the site area physically lying between them, can be taken as a reasonably reliable estimate of the on-site background level at any particular time that accounts for the specific wind speed, direction, time of day and atmospheric conditions prevailing during that 10 minute period.

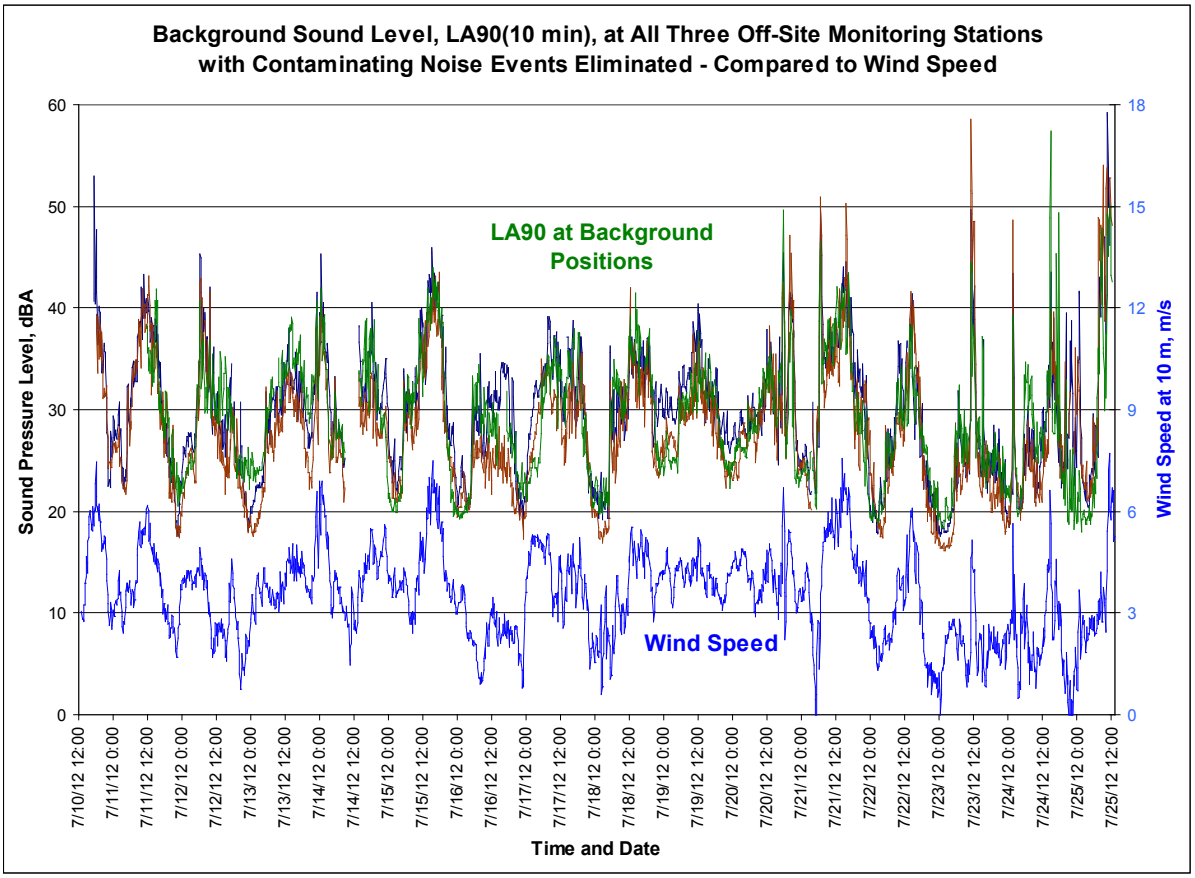

Figure 3

The data in Figure 3 have been edited to remove noise spikes that were observed only at one position and not at any others, indicating a contaminating local noise event that is not representative of the area as a whole. Spikes were also deleted (from both the on-site and background data) if there were no concurrent spike in wind speed, even if they may have occurred at multiple locations, on the premise that the noise was not associated with the turbines and may have been due to thunder, rain, a helicopter flyover or some other area-wide noise event.

The results shown in the Figure 3 example are not unique to that site and a similar consistency between the off-site proxy location sound levels has been observed at a number of other projects in rural areas even though the background monitors are deliberately set up in diverse settings.

Figure 4 compares the average (design) background level measured at the three proxy positions to the total sound level measured at a typical on-site receptor position. The noise spikes at A through D are clearly local noise events that cannot be ascribed to the project since there was no simultaneous gust of wind; however, spikes E – I are evidently related to the wind and would normally be put down in their entirety to the turbines if it weren't for the fact that these peaks are matched or exceeded in magnitude with concurrent spikes at the background positions (see Fig. 3). Consequently, the proxy background measurements show that not all of this noise was due to the project and its sub-component contribution to the total can generally be calculated. This is particularly significant in this case because the regulatory limit for this project was 50 dBA at non-participating residences.

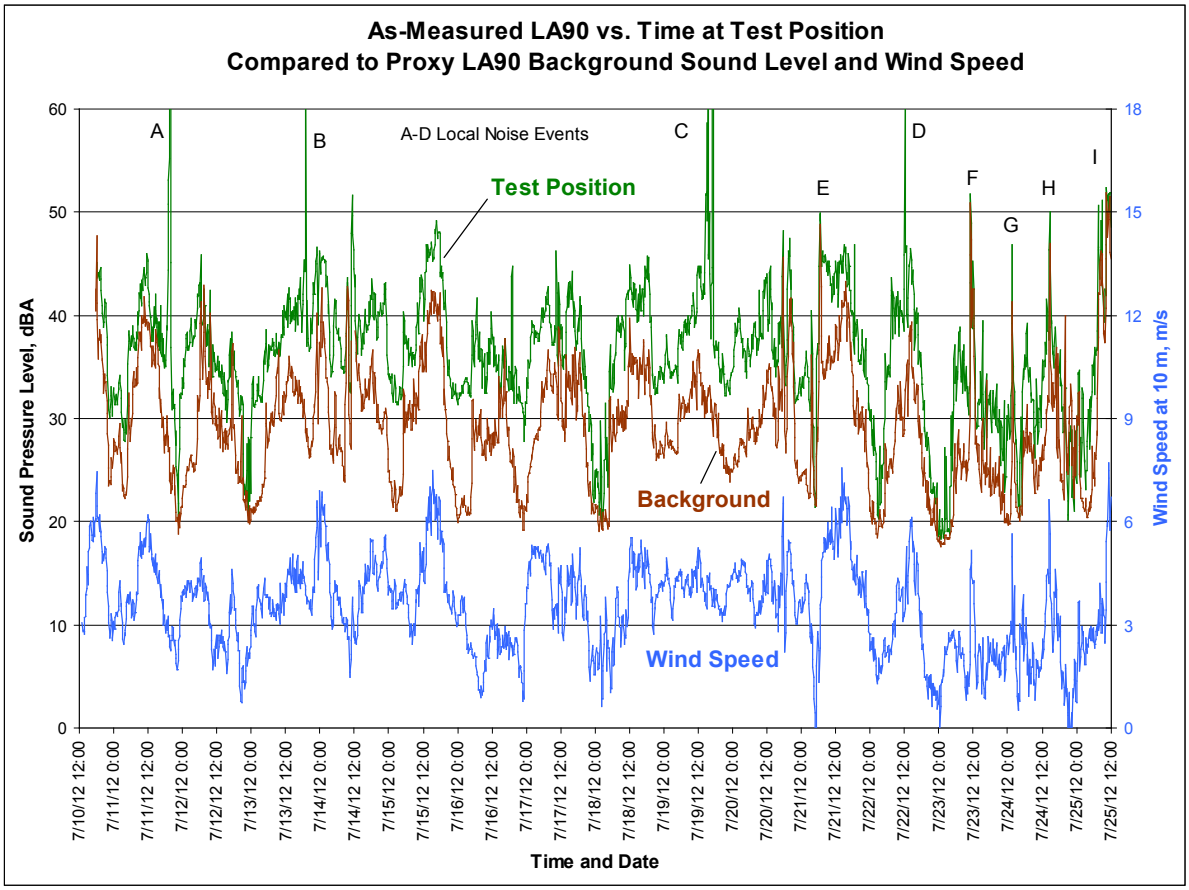

Figure 4

Figure 5 shows the nominal project-only sound level over the survey period after correction for background and the elimination of periods when the project was idle.

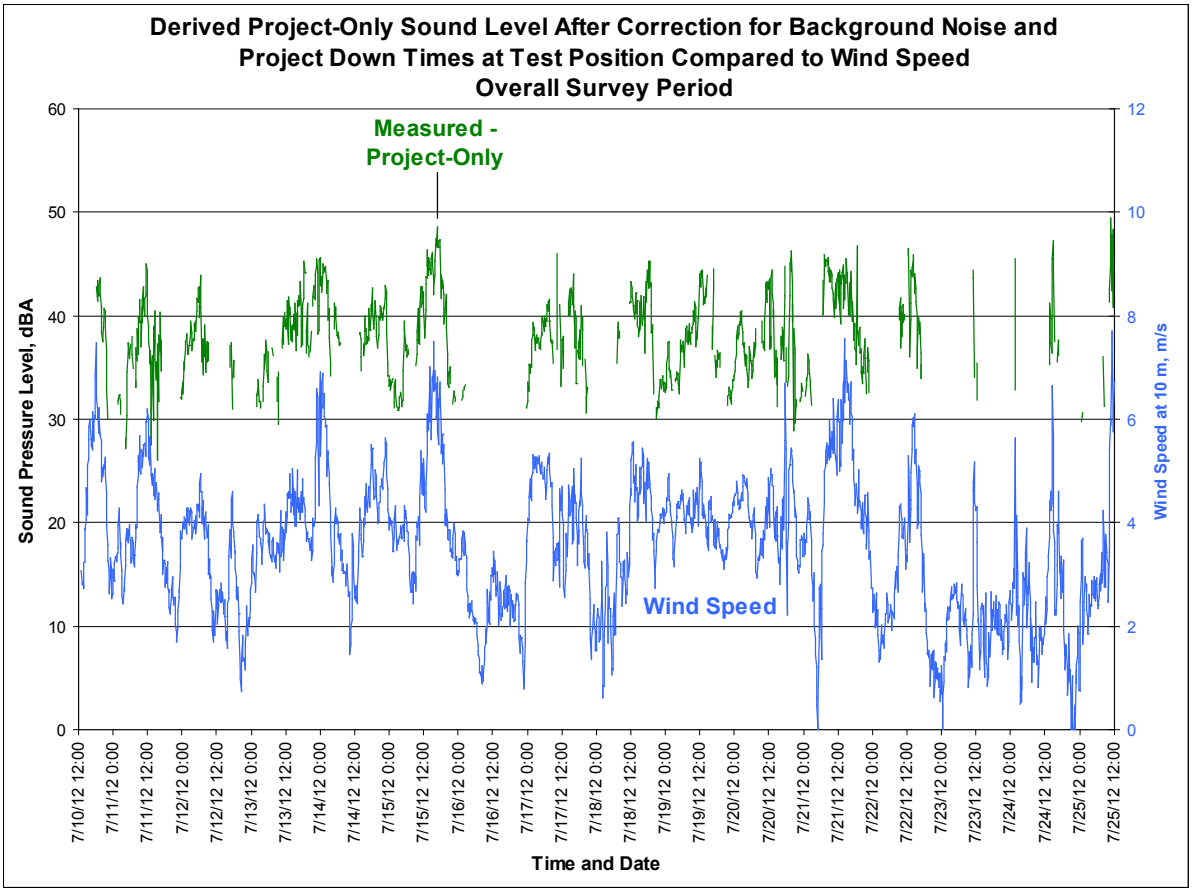

Figure 5

This result shows that, despite apparent indications to the contrary in the as-measured levels at this receptor point, the project-only sound level did not exceed, at least on a sustained basis, the 50 dBA limit during the noise peaks at E – I in Figure 4 or at any other time.

Conclusions

Background sound levels without any turbines present at typical wind turbine sites in rural areas commonly range from 25 to 55 dBA depending largely on wind speed, which means that background noise is often comparable to the project-only sound level at neighboring residences and therefore cannot be neglected when measuring operational noise; particularly during regulatory compliance testing. During the type of long-term monitoring survey necessary to measure wind turbine sound levels under a variety of wind and weather conditions it is not generally practical to shut down the project intermittently to obtain background levels nor it is appropriate to use the background level measured during calm conditions when the project is idle to represent the background level during windy conditions. Instead, a technique is suggested where off-site monitors are set up to measure background levels on a continuous basis throughout the survey for use in correcting the on-site measurements for background noise.

Numerous pre-construction surveys at future wind project sites indicate that a fairly uniform ambient sound level typically exists over wide areas in rural settings. Consequently, measurements at diametrically opposed off-site positions are often similar at any given time allowing the average level to be used as a representative background level for all on-site positions, which are physically situated between the off-site "proxy" measurement points. This approach has the important advantage of developing a time history of the approximate background sound level over the entire survey period of several weeks. Thus the background sound level measured under identical and concurrent wind and atmospheric conditions is used to correct the measurements made at the same time at on-site receptors yielding the project-only sound level.

References

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