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Compliance Checking procedure for Wind Farms Environmental Noise Guidelines

Valeri V. Lenchine

Science & Sustainability Division, Environment Protection Authority of SA,
GPO Box 2670 Adelaide SA 5001, Australia

ABSTRACT

Many governmental strategic plans encourage the use of renewable energy sources. Responding to industry needs, the Environment Protection Authority of SA introduced Wind Farms - Environmental Noise Guidelines (Interim) 2007. The core objective of the Guidelines is to balance developments in the wind farms sector with the level of amenity expected by the surrounding community. Situations where the existing background level is comparable, or exceeds, wind farm noise are common. The submitted paper aims to consider a few methods that might be incorporated into the Guidelines as a compliance checking procedure and can be used to provide an adequate measure of the wind turbines noise contribution against background and other sources within a vary quiet rural environment. The methods do not require employment of complex techniques, special instruments or advanced data post-processing. International and national practice and results of wind farm noise monitoring are taken into account to develop the compliance checking procedures.

INTRODUCTION

At present South Australia considers a number of applications to establish new wind farms. The State Strategic Plan encourages use of renewable energy sources and highlights development of regulations and guidelines preventing excessive noise exposure on noise sensitive areas. It is important to promote wind farms development using contemporary assessment approaches to preserve environment and human well-being. The EPA Environmental Noise Guidelines aims assisting developers, planning and governmental authorities and the general community to evaluate noise impact from wind farms. The Guidelines were originally published in February 2003 with the intention to review the Guidelines in the near future. During 2005 and 2006 preliminary compliance research and two round of public consultation were carried out. Responses to the consultation were received from the public, the wind farm industry and acoustic consultants. The preliminary research identified that further investigations regarding compliance checking methodology was required. As a result of the findings and consultation responses the guidelines were replaced in December 2007 by Interim Guidelines with a commitment to publish updated and completed Guidelines by the end of 2008. The 2007 Interim Guidelines did not contain a compliance checking procedure. During 2008 a new compliance checking procedure was verified using a case study. As there is no widely accepted regulation with respect to the environmental impact imposed by the wind farms operations, there are still controversial issues that should be addressed. Concerns expressed by the industry centred on whether the existing compliance methodologies could provide an adequate measure of the true contribution of wind turbine noise emissions against other sources (natural background, farming activities etc). Our recent investigations try to address this issue.

REQUIREMENTS FOR THE COMPLIANCE CHECKING PROCEDURE

It was considered a few methods might be incorporated into the Guidelines as a compliance checking procedure. There is no doubt that contemporary scientific methods and instrumentation can find a way to separate the contribution of a wind farm and other sources. However a method or procedure included as a part of a statute should meet certain requirements. Preferably the methods should not require employment of complex measurement techniques, special instruments or advanced data post-processing. International and national practice and results of wind farm noise monitoring are taken into account to develop the compliance checking procedures.

WIND FARM NOISE DATA ANALYSIS

SPL descriptors

Prediction of the wind farm noise is usually made using A-weighted equivalent sound pressure level L_{Aeq}. Modelling is generally performed for the worst case weather scenario (wind is blowing from the noise source toward the receiver). These conditions may not occur often during the operation of the wind farm, therefore, the prediction can be considered as an upper estimate of the environmental noise impact.

Assessment of the wind farm noise might be difficult due to the masking effect of the ambient noise, transient events and its influence on the noise level descriptor (L_{Aeq}). National standards and research reports recommend using statistical descriptors instead of L_{Aeq}. It allows mitigating the effects mentioned above. Previous Guidelines used L_{A90} descriptor (measured during 10 minutes intervals) for the compliance checking procedure. Dependence of the noise descriptor on the wind speed is derived from matched sound level and wind speed pairs as a result of a curve fitting process where the approximating curve is chosen from a set of permissible functions with a higher regression correlation coefficient (coefficient of determination R^2).

Some investigations try to find connection between the two noise descriptors. For example, New Zealand Standard NZS 6808:1998 indicates that the difference between statistical descriptor L_{A95} and the equivalent sound pressure level (SPL) is typically 1.5~2.5dBA. It is expected that the difference between L_{Aeq} and L_{A90} descriptors should be even less as L_{A90} is higher than L_{A95}. However the measurement results from our monitoring sites show that the correction factor to convert one descriptor to another is hardly predictable. The difference between the descriptors for data gathered during our recent noise monitoring program is 1.8~4.8dBA depending on the wind speed, data truncation, filtering, etc. Curves corresponding to the descriptors (derived from the measured data by the polynomial fitting) can be seen in Figure 1. Most likely the correction value is a function of many factors and might be unique for each type of wind turbine generator (WTG), the topography and environmental conditions. It would be practically impossible to use a universal correction factor to perform transition from one noise descriptor to another.

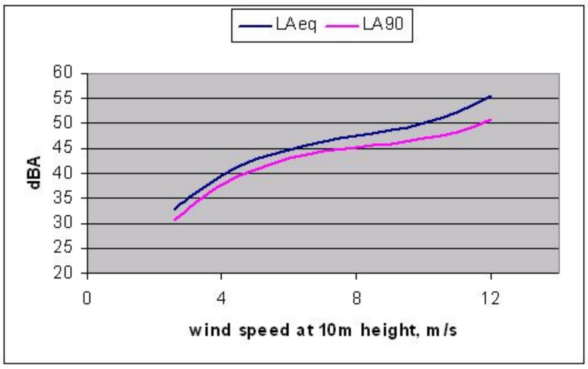

Figure 1 Noise descriptors measured 125m from WTG tower

Data post- processing

As it was mentioned before, prediction of the wind farm noise is usually based on the worst case scenario. Some of the recommended noise monitoring practices do not take into account this fact. For instance Standard NZS 6808:1998 permits of the post-processing of a full set of data, including all wind directions and SPL/wind speed pairs. Noise measured below the WTG cut-in speed and at high wind speeds (above speed of the rated power) can affect the resulting SPL curve. The post-process is usually performed on a truncated set of data where noise measurements during rain periods and known extraneous noise events are disregarded. Some investigstions propose the exclusion of data below WTG cut-in speed and higher than the speed of the rated power from the regression analysis to improve accuracy of the curve fitting within the range of the wind speeds where the wind farm noise might be an issue.

Majority of the sound propagation predictions are based on a worst case wind direction scenario. Some noise monitoring procedures also include this specification for the compliance checking or the resolution of noise complaints. ISO1996-2 specifies the worst case wind direction within an angle of ±45º from a line connecting the centre of the dominant noise source and the centre of the receiver region. This description of the downwind propagation condition is found to be practical and implemented in many documents and recommendations. It should be noted that the last requirement might significantly reduce the amount of data available for analysis. Situations when the wind blows from the nearest WTG towards the receiver might be very rare. In this case the relevant authority can decide how many data pairs are sufficient to make the noise assessment.

Our recent investigation shows that truncation of the noise data set in accordance with the range of the wind speeds and worst case wind direction can bring variations in the noise levels calculated from the curve fitting process. Typical deviation is generally less than 3dBA (see Figure 2) but can reach 5dBA for particular wind speeds. This generally reasonable deviation can be important in case of legal disputes. Therefore an official compliance checking procedure should contain clear specification on the data analysis.

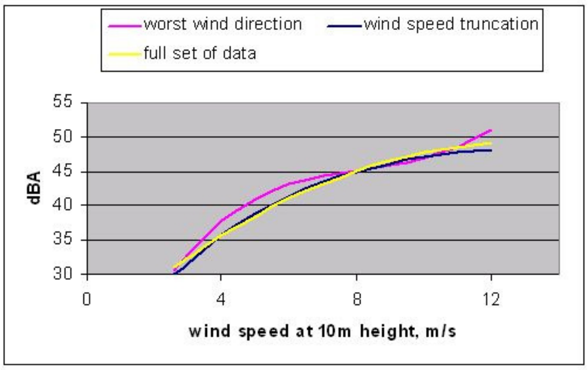

Figure 2 Comparison of L_{A90} regression curves based on different set of data

The regression curve equation is one more factor influencing accuracy of the noise data analysis. Many recommendations state that linear and polynomial up to 3rd order analysis is sufficient to choose the approximating curve. Other procedures involve broader range of possible functions which involves exponential or logarithmic functions. The regression correlation coefficient serves as criterion in selecting which of the curves is the best fit.

Analysis of many data sets brings evidence that increase of the polynomial order for the fitted curve does not lead to significant increase in the correlation coefficient of regression. Generally R^2 value for L_{A90} is higher than for L_{Aeq} descriptor if measured at the same location. In spite of the fact that there is also slight incremental trend for the correlation coefficient with increase of the order for the polynomial fitting, the curves with higher polynomial order might result in improbable character of the curve. Usually noise generated by WTG increases for higher wind speeds as well as background and total noise. Sometimes transition from linear dependence to the polynomial curve leads to presence of few maximum and minimums and inconsistency of the measured noise with characteristic of the WTG as a noise source. It should be one more indicator in choosing the correct fitting curve.

Wind speed and direction measurements

The collected noise data should be analysed against wind speed measured at the dominant noise source. Many procedures specify reference height of 10m for the wind speed and direction measurements. In Figure 3 wind speed data from in-built WTG wind speed sensor is scaled from 70m height down to 10m using a conventional wind shear model. Figure 3 also shows comparison of 10m wind speed indications and wind speed calculated from 70m height measurements. It demonstrates reasonable compliance with 10m mast wind measurements. Generally divergence of the calculated values from the measured ones becomes greater for higher wind speeds. Compliance of the calculated results with wind speeds measured at tower is expected to be better as the height difference is less. However our recent investigation shows that compliance of the results scaled down from the wind sensor at 60m height is even worse. This can be due to larger distance separation between 10m hydraulic mast and the meteorological tower. Therefore the higher discrepancy in the calculated results can be due to non-uniformity of the wind speed across the wind farm site.

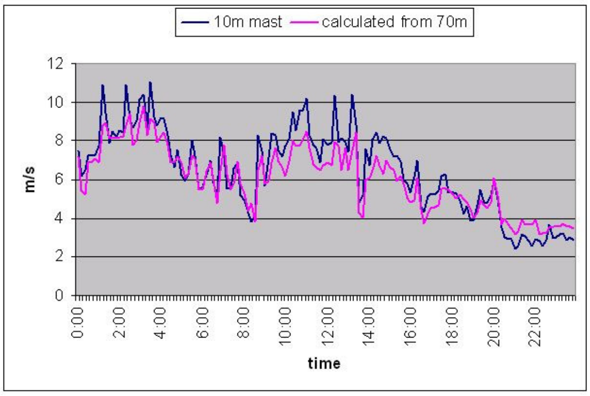

Figure 3 Comparison of wind speed data for one day

As it is good to have the wind measurement reference height for cross-analyse of noise measurement data between different wind farms, it is difficult to find any justification of 10m wind speed monitoring requirement for single site measurements. Reporting of the SPL levels versus wind speed at the WTG hub height might be more appropriate since it does not involve the wind speed conversion error.

COMPLIANCE CHECKING METHODS

Information obtained during the noise monitoring should be sufficient to make a judgement about environmental noise impact from the wind farm. Our research is concentrated on a few possible procedures that can be included as a part of the compliance checking procedures.

Correction for background

One of the standard approaches to extract the wind farm noise is the correction for background noise. This method is incorporated into many standards and procedures. The method is based on the logarithmic subtraction of the previously acquired background noise level L_b from the combined noise level measurements L_R. Wind farm noise L_{WF} is calculated as follows:

$$L_{WF} = 10\log(10^{L_R/10} - 10^{L_b/10}), \quad (1)$$

Frequently background monitoring is performed before the wind farm construction. Compliance checking measurements might follow few years later. Validity of the background noise monitoring becomes very important under these circumstances. Seasonal variations in the background level and changes at the measurements locality might affect the calculated wind farm noise. If the combined wind farm and background noise is below the background values for the wind speeds within the operating range of the WTGs, it is a good indicator that the background data can not be utilised to detect the wind farm contribution. Figure 4 shows such a situation when the method can be used for the wind farm noise calculation at high wind speeds. The total noise is below the background noise measured at low wind speeds (but above the cut-in speed of WTG). The background noise was acquired a few years before the latest monitoring. Most likely the background noise changed significantly since then and the correction for background method can not be used to detect the wind farm noise at any wind speed. New background measurements should be arranged in this case.

Some procedures propose starting and stopping the WTGs to gather new background data. This method requires assistance of the wind farm operator and might be very expensive. The background noise investigations in accordance with the start/stop method are based on the limited statistics and might not be accurate. In this case other methods can be considered as an alternative.

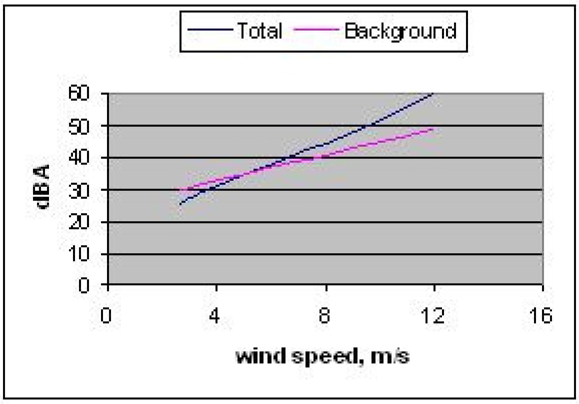

Figure 4 Comparison of total noise and background measurements at the monitoring site (L_{A90} descriptor)

Correction for the reported sound power

The main equation for atmospheric sound propagation can be written in a simplified form where sound pressure level L_p at some point from the source can be calculated as follows:

$$L_p = L_{PF} - A_{tot}, \quad (2)$$

where L_{PF} is the source sound power and A_{tot} is the total attenuation due to geometrical divergence, air absorption, ground attenuation etc. Usually wind farms have installations of the same type and only WTGs nearest to the receiver bring significant contribution to the noise. Contribution from each of the WTGs is estimated by the formula above where dependence of the sound power L_{PF} versus the wind speed is the same for all of the WTGs. The total attenuation is generally different for each of the turbines and depends on many factors such as separation distance between the sound source and receiver, topography etc. The total contribution from a group of noise sources would be similar to (2) where the radiated sound power for particular wind speed can be taken from the manufacturer data.

It is difficult to organise repeated background noise monitoring after the commissioning of a wind farm. Existing *Wind Farms Environmental Noise Guidelines* recommend acquiring not less than 2000 pairs of valid data to perform the background curve calculations. It is equivalent to about 2 weeks of monitoring during which the wind farm should be in stop mode. However it is possible to get a reasonable amount of data during post-construction measurements at wind speeds below the cut-in speed where SPL magnitudes indicate the background level. Considering that the measured background noise levels at wind speeds 10% less than the cut-in speed is approximately the same as at the cut-in speed, it is possible to derive the initial background level L_{b0}. Sometimes the data set does not contain values at exactly 0.9 of the WTG cut-in wind speed. It is proposed to derive the initial background level as mean square SPL ($L_{A90,10}$, statistical descriptor measured during 10 minutes) for within ±5% tolerance interval:

$$L_{b0} = 10\log(\frac{1}{n}\sum_{1}^{n} 10^{L_{A90,10i}/10}), \quad (3)$$

where n is the number of measurements at the specified wind speeds. Then the wind farm noise can be calculated for the cut-in speed as follows:

$$L_{WF0} = 10\log(10^{L_{R0}/10} - 10^{L_{b0}/10}), \quad (4)$$

where L_{R0} is the combined wind farm and background noise level at the relevant receiver at the cut-in wind speed. Wind farm noise can also be expressed as:

$$L_{WF0} = L_{PF0} - A_{Wtot}, \quad (5)$$

where A_{Wtot} is the total attenuation of the sound propagation from the wind farm. A similar equation can be written for the next integer wind speed:

$$L_{WF1} = L_{PF1} - A_{Wtot}, \quad (6)$$

where L_{PF} is the source sound power. Then the wind farm noise level L_{Wi} is calculated for each of the integer wind speed above the cut-in speed up to the speed of the rated power using expression:

$$L_{WFi} = L_{WF(i-1)} + \Delta L_{P(i-1,i)}, \quad (7)$$

where $L_{WF(i-1)}$ is the wind farm noise level for the previous integer wind speed (or for the cut-in speed for the first integer speed calculation), $\Delta L_{P(i-1,i)}$ is the sound power correction defined as the difference in the reported sound power levels of the WTG at the wind speed being considered and previous integer speed (or cut-in speed for the first integer speed calculations). The equation above can be derived from a system of two sound propagation equations similar to (5) and (6) admitting that the total attenuation does not vary with a small change to the wind speed.

Directional noise monitor is one of the recent advancements in noise monitoring techniques. During our recent noise monitoring program, BarnOwl directional monitor was utilised in addition to noise loggers and wind monitoring stations as a reference instrument since it allows the detection of noise contribution from particular directions with angle resolution 5°. Comparison of data from the directional noise monitor and the calculated contribution from the wind farm demonstrates good compliance with the correction for the reported sound power method (see Figure 5).

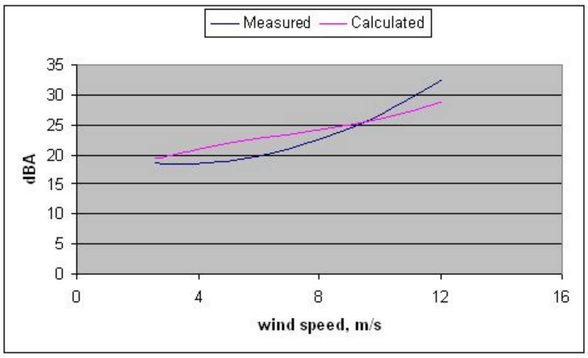

Figure 5 Comparison of wind farm noise measured by the directional monitor and calculated by the correction for sound power method

Correction for the reference SPL

Similar to the section above, measurement of the SPL at the reference point near the WTG could be used instead of the reported sound power level. It is assumed that measurements taken close to WTG mainly represent noise from the WTG. The procedure can be useful in case there is no reliable sound power data for the WTG used or the wind farm comprises different types of WTGs. Figure 6 represents measurements made at a distance of 125m from the WTG tower towards the receiver. It shows an increase of the WTG SPL over 20dBA if the wind speed varies from the cut-in speed to 12m/s. It is scarcely possible if the reported sound power varies less than 10dBA at the same time (see Figure 6). Most likely the reference point measurements are significantly affected by operation of other WTGs, local topography and extraneous noise sources. To be valid, the reference point should satisfy the following conditions:

- topography should have minor influence on the SPL measurements, i.e. the measurement point should be located on a plane surface without significant roughness;
- natural background noise at the point should be insignificant in comparison with the WTG noise;
- extraneous noise should not distort the measured SPL.

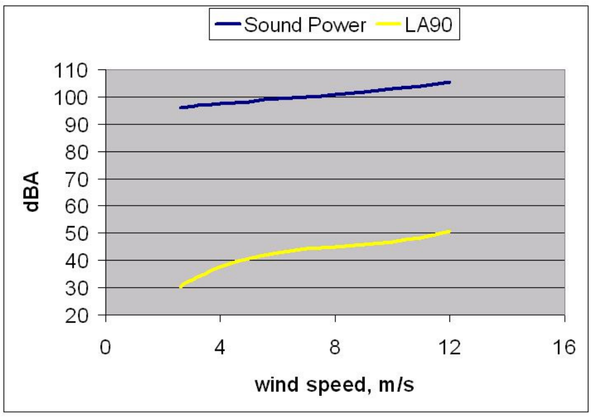

Figure 6 LA90 measurements at 125m from WTG tower and reported sound power level

If requirements above are met, SPL at the reference point should represent sound propagating toward the receiver with sufficient accuracy.

Obviously measurements at the reference point should be consistent with the reported sound power characteristic.

Sometimes it would be difficult or impossible to allocate such a point at the nearest to the receiver WTG.

SUMMARY

The paper aims to consider a few methods that might be incorporated into the Wind Farms Environmental Noise Guidelines as a compliance checking procedure. It also includes basic requirements that should be met by the technique in question. The compliance checking procedure should provide an adequate measure of the true contribution of wind turbines emissions against background and other sources within a very quiet rural environment. Case studies are taken into account to develop an appropriate procedure. It shows that the conventional correction for background technique can be used in case the previously measured background data are valid. The correction for the reported sound power method can be utilised as an alternative procedure if acquisition of valid background noise levels is not possible. Calculation of the wind farm noise is possible by correction for the reference point SPL method. However implementation of the latest method requires a few conditions to be met, otherwise accuracy of the correction for the reference point SPL is doubtful. Two other methods demonstrate good agreement with results of the case studies.

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