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Wind turbine noise measurements - How are results influenced by different methods of deriving wind speed?

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Summary

With the increasing number of operational wind turbines, the number of noise measurements required to demonstrate compliance with planning conditions is rising as well. Noise limits are often set relative to wind speed and therefore the assessment of noise from wind turbines requires simultaneous noise and wind speed measurements. For financial reasons, smaller and single turbine sites are often not equipped with a meteorological mast. If no mast mounted anemometry is available, wind speed can either be taken from nacelle anemometer or derived from the power output combined with the power curve for the respective wind turbine type.
In the presentation, noise measurements referenced to nacelle anemometer data will be compared with the same measurements correlated with derived power curve wind speed, and measured wind data from a separate met mast or other remote sensing devices. The influence of incorrect filtering of wind data for shadow effects (mast and/or nearby wind turbines) on the noise assessment will also be presented. The advantages and disadvantages of the various methods are discussed.

1. Introduction

In countries where wind turbine noise limits are set relative to wind speed, it is essential to obtain the correct wind speed during wind turbine noise measurements in order to verify whether the noise limits set out in planning conditions are being met or exceeded. In the UK, ETSU-R-97 *The Assessment and Rating of Noise from Wind Farms* is generally used to assess wind farm/turbine noise at the nearest noise sensitive properties at the planning stage. In this document the method for deriving noise limits is to undertake a survey of the background noise at locations representative of each affected property and set the limits relative to the prevailing background noise with a margin of + 5 dB, if predicted wind turbine noise levels are greater than 35 dB $L_{A90,10\ min}$. The prevailing background noise is calculated from a regression curve calculated from the measured noise correlated with wind speed measurements at the wind farm site. Lower fixed limits apply for day- and night-time for very low noise environments. Since the wind turbine noise and the noise limits are wind speed dependent, the knowledge of the correct wind speeds is important for any wind farm noise assessment.

Where reference is made to wind speed, it is also essential to define the height to which the wind speed refers, in order to compare measurements taken before and after the wind farm is built, and to compare noise measurements with turbine noise.

Wind speed in wind turbine sound power level documents is often given with reference to 10 m height. This is often arbitrarily referred to as 'measured at 10 m height' or similar whereas, in fact, the quantity it refers to is hub height wind speed 'standardised' to 10 m height wind speed using a logarithmic wind profile and a roughness length of 0.05 m. ETSU-R-97 generally refers to 10 m height wind speed, however, since the publication of Van den Berg's *The sound of high winds: the effect of atmospheric stability on wind turbine sound and microphone noise* (Van den Berg 2006) it has been generally acknowledged that extrapolating wind speed measured at 10 m height to hub height wind speed underpredicts the actual wind speed as it does not consider site-specific wind shear and atmospheric stability. This has now been taken into account in the recently published UK Institute of Acoustics' *Good Practice Guide to the Application of ETSU-R-97 for the Assessment and Rating of Wind Turbine Noise* (GPG 2013) which describes the preferred method for wind speed derivation to be the one that references noise limits to 'standardised' 10 m height wind speed derived from wind speed measurements at hub height in line with the way source noise levels are described.

Not all operational wind farm sites have tall meteorological masts installed to monitor wind speed and direction during the wind farm's operational life. Therefore alternatives have to be found when assessing wind farm related noise at residential properties against wind speed dependent noise limits. Various methods of measuring or deriving wind speed are described below.

2. Methods of Wind Speed and Direction Measurement

2.1 Meteorological Mast

A well sited meteorological mast with an anemometer and wind vane at hub height should give representative measurements of wind speed and direction experienced by wind turbines on the site. However, care needs to be taken of wake effects from the wind turbines, and turbulence and shadow effects caused by other obstacles upwind of the anemometer. The measured data needs to be filtered appropriately.

If the mast is lower than the turbine hub height, the hub height wind speed can be calculated from measurements at two different heights by calculating the wind shear exponent between those two heights and deriving the hub height wind speed using an exponential wind profile.

The hub height wind speed can subsequently be 'standardised' to 10 m height wind speed by using the standard roughness length of 0.05 m. The calculation methods can be found in IEC 61400 *Wind Turbines - Part 11: Acoustic noise measurement techniques Ed.3* (2013) amongst others (IEC61400-11Ed3).

Smaller schemes may not have a permanent met mast on site or, in some cases, planning permission for a tall mast may have expired before the wind farm was built and therefore no tall met mast data is available. Unless noise limits are explicitly referenced to measured 10 m height wind speed, a 10 m met mast should not be used. Standardised and measured same height wind speed are not directly comparable. Occasionally, measured 10 m height wind speed may be converted to standardised 10 m wind speed with average wind shear values from a long period (minimum of 1 year) but this method has its own pitfalls and will not be discussed further in this paper.

2.2 Hub Height Wind Speed from Power Curve or Nacelle Anemometer

Most large wind turbines have cup or ultrasonic anemometer mounted on the nacelles, mainly for the turbine controller to establish cut-in and cut-out wind speed and for pitch regulation of the blades where applicable. This data is usually available in 10 minute averages from the turbine manufacturer or the site operator. This method may be inaccurate unless it can be determined with certainty, whether the anemometer output is corrected for the presence of the passing blades in front of it. Certainly during shut-down periods for background noise measurements a blade stationary in front of an anemometer gives false readings.

More accurate is the method described in (IEC61400-11Ed3) for derivation of wind speed from a measured or calculated power curve during wind turbine operation. This requires obtaining the electrical output of the turbine during operation. However, this method is not suitable for wind speeds outside the 'allowed' range, i.e. at the lower and higher end, when the slope of the power curve gets too shallow. For higher wind speeds than that when the turbine approaches full rated power, this method provides no meaningful wind speed values. For data points above the 'allowed' range, however, the wind speed can be taken from the nacelle anemometer which is to be calibrated in-situ against the power curve derived wind speeds.

This method requires a measured or calculated power curve (in particular smaller wind turbines may not have a power curve available) and operation in the corresponding settings to the supplied power curve. If the turbine is running in a different mode during the survey, for example due to a technical fault, this method may no longer be applicable. If the turbines are operatied in noise reduced modes for reasons of mitigating the noise impact, a power curve for such a mode is required.

2.3 LiDAR and SoDAR

LiDAR (Light Detection And Ranging) and SoDAR (Sonic Detection And Ranging) have established themselves as stand-alone wind speed and direction measurement devices. They have the advantage that they can measure wind speed and direction at a wide range of heights unlike anemometry mounted on met masts whose height cannot be changed without taking down the met mast or rearranging beams, so that hub height wind speed can usually be measured directly. They are mobile and can be placed on the wind farm site in a location where influence from the wind turbines and other obstacles can be minimised.

3.0 Preliminary results

3.1 Comparing two cup anemometer mounted on a met mast at the same height
It may seem obvious but it should be pointed out that data from any anemometer mounted on a beam at any other height than the very top, needs to be filtered to remove wind directions corresponding to it being in the shadow of the mast. The following graph shows two anemometer mounted at the same height with clear shadowing effects. Wind speed measured in the shadow affected wind direction is shown to be too low compared to the wind speed from the unaffected anemometer. If the wind flow on the anemometer is not affected, the ratio of the two anemometer should be 1 for all other wind directions. The effect of the tower on the anemometer in its shadow can clearly be seen in Figure 1. The anemometer were mounted facing north and south.

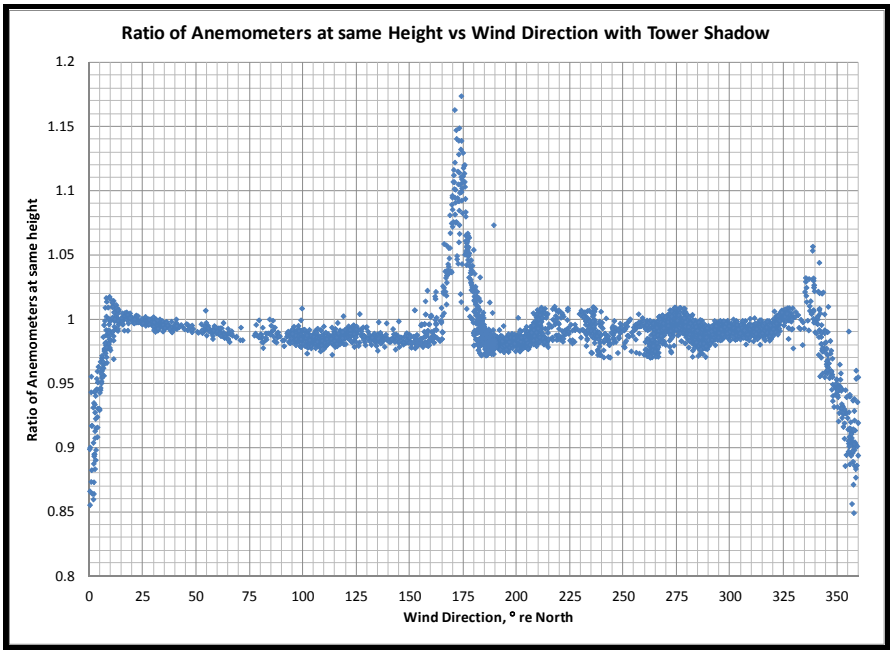

Figure 1: Shadow Effect of Tower on Anemometer

The met mast location plays an important role for the correctness of the wind data. Poor siting (in the wake of wind turbines, near tall obstacles etc.) and wear and tear of the bearing can cause further effects on the measured wind speed.

3.2 Comparing SoDAR wind measurement with cup anemometer on met mast and anemometer mounted on wind turbine nacelle

On another wind farm site a SoDAR device from Secondwind, the Triton wind profiler, was set up alongside a met mast which has been in operation since before the wind farm was built. Neither of the instruments had been calibrated since the installation, which is why the Triton was used to check the performance of the cup anemometers. The Triton was sited in accordance with the specification of the manufacturer for comparison of Triton with met tower measurements (Walls 2010). The data showed a great spread in sectors where the met mast was downwind from a wind turbine and those were excluded from the correlation. After this filtering, the data showed a good correlation with slight underreading from the anemometer. However, this was more accurate than the wind speed reading from the nacelle anemometers as will be discussed below.

The Triton wind speed was correlated with the nacelle anemometer of the wind turbine closest to the residential property where the noise study was undertaken. The rationale behind using data from this turbine was that the noise emission of the closest turbine would have the greatest influence on the measured noise level at the property. The Triton position was approximately equidistant from the met mast and the wind turbine. Both may have experienced some wake effects from another turbine further upwind. Firstly the data was only filtered for periods of turbine shut-downs as the nacelle anemometer was not considered accurate for those periods due to blade effects mentioned earlier. This resulted in a regression curve rather than a linear correlation with the difference between Triton and the nacelle anemometer being about 1 m/s for wind speeds below 14 m/s (nacelle anemometer reading lower) which decreased for higher wind speeds until it matched up at 17 m/s. This upper part was outside the normal measurement range so that for the purpose of the wind farm noise assessment, the discrepancy was 1 m/s. Subsequently sectors where the

wind turbine or the Triton were in the wake of another wind turbine were also excluded from the correlation which resulted in a linear regression. At lower wind speeds the same 1 m/s difference was found, however at 10 m/s the nacelle anemometer was reading 1.5 m/s lower and at 12 m/s the difference had increased to 2 m/s.

Figure 2 shows measured wind farm noise with standardised 10 m height wind speed derived from the SoDAR measurements. Figure 3 shows the same noise data with standardised wind speed derived from the nacelle anemometer of the closest wind turbine and Figure 4 shows the data with wind speed derived from the average of all wind turbine nacelle wind speeds over the operational range.

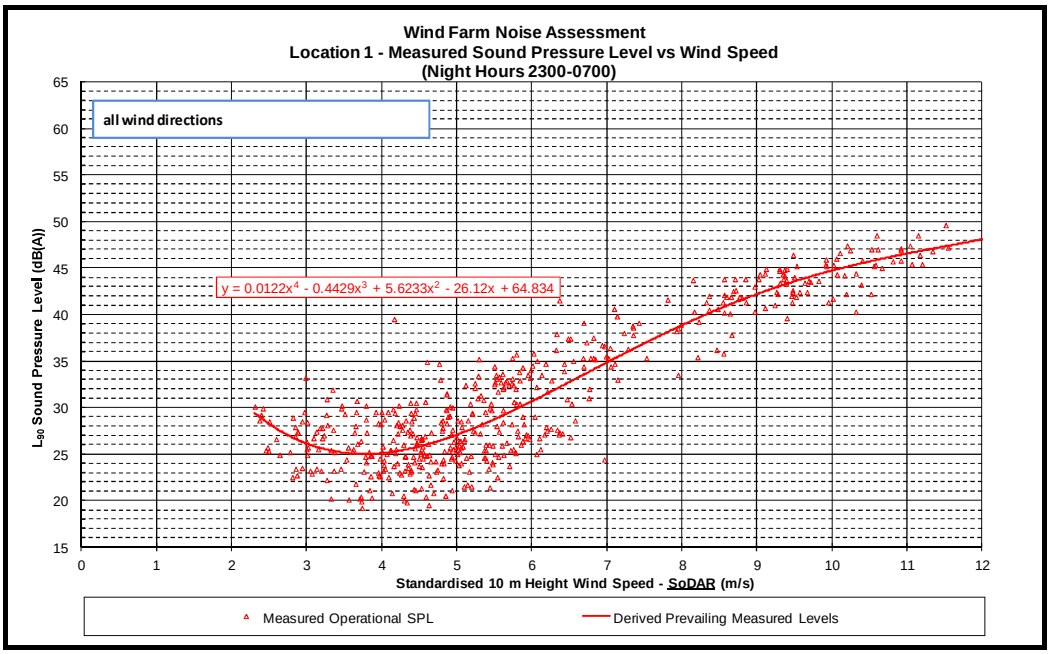

Figure 2: Wind Farm Noise Assessment with SoDAR wind speed

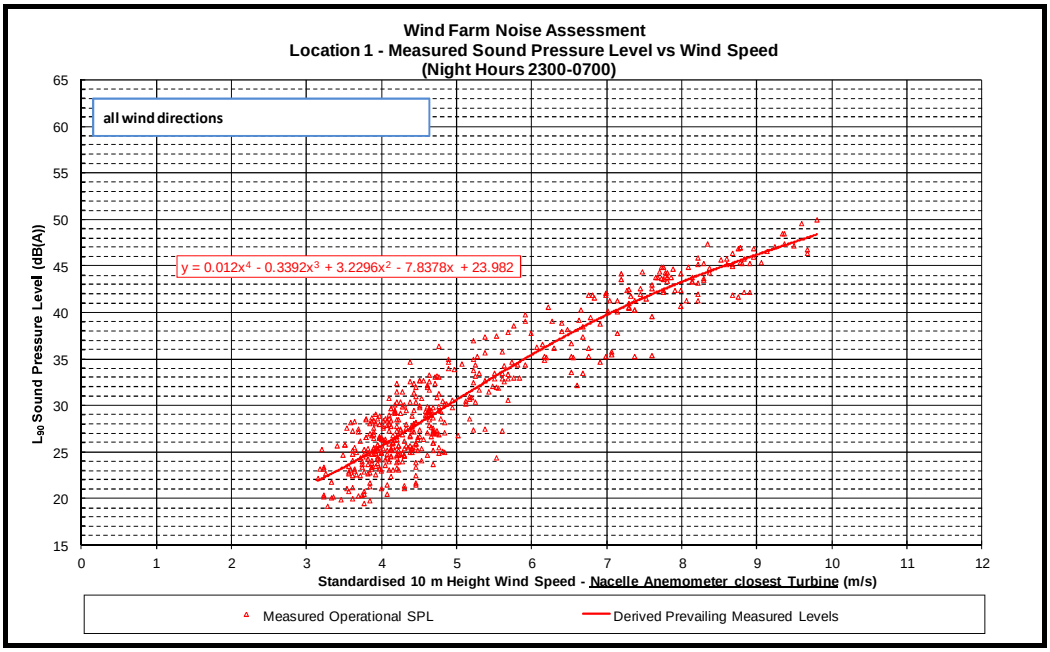

Figure 3: Wind Farm Noise Assessment with Wind Speed from Nacelle Anemometer of the closest Wind Turbine

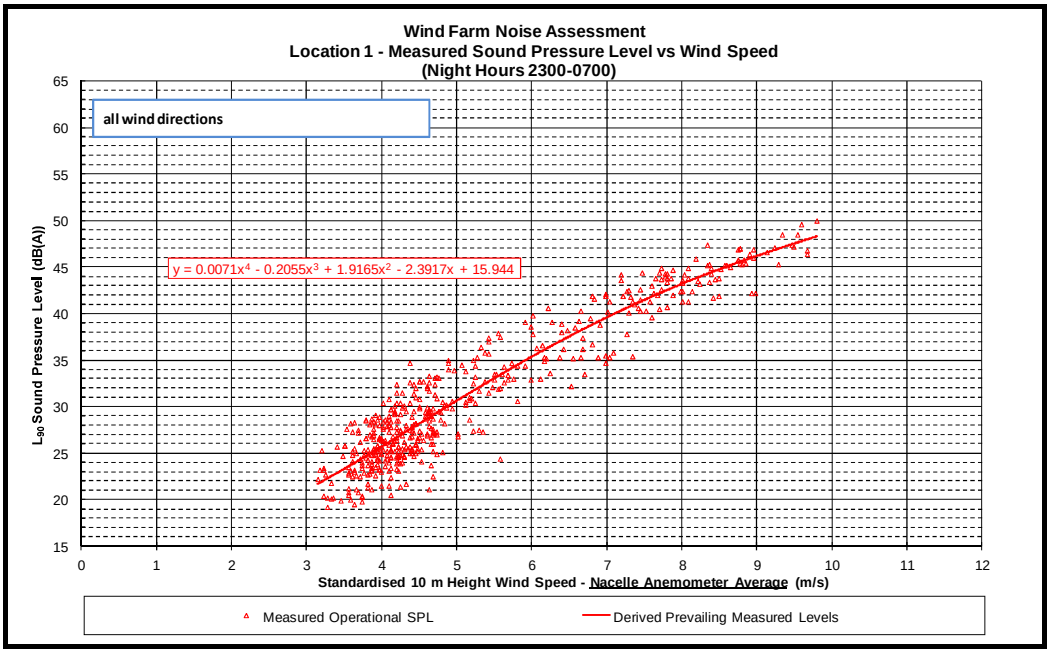

Figure 4: Wind Farm Noise Assessment with Average Wind Speed from all Nacelle Anemometer

It can be seen that the data cloud does not differ significantly between Figure 3 and 4 but that there is a clear change of shape between the SoDAR and the nacelle anemometer wind speeds. The data range is smaller, it looks more compressed. The difference between averaging and the single nacelle anemometer is 0.2 dB at the most. The wind farm site consisted of three wind turbines on 50 m hubs. Results for large wind farm sites will probably differ as it is expected that the wind speed across a larger site may vary more.

Figure 5 shows the curve of the three assessment charts in one chart for easier comparison.

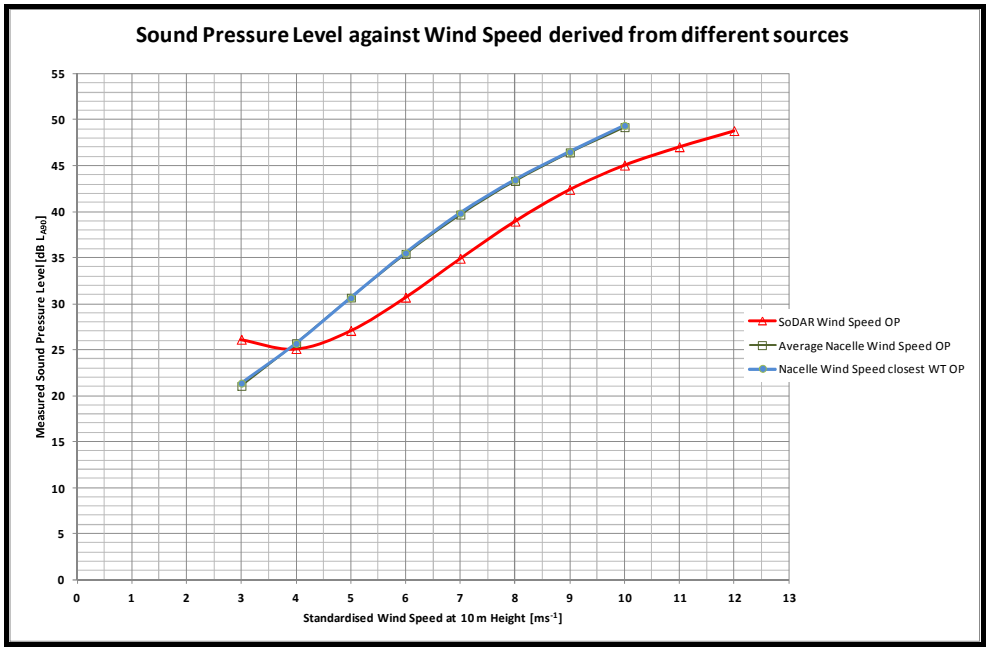

Figure 5: Wind Farm Noise Assessment with Wind Speed derived with three different Methods

The maximum difference of derived noise levels per integer wind speed between the regression curve for nacelle anemometer and SoDAR derived wind speed is 4 dB at wind speeds of 6 and 7 m/s, usually the critical wind speed range for compliance and complaints measurements.
So far this assessment has only been carried out for one wind farm site consisting of three medium sized wind turbines. Therefore no general statements can be made. More wind farm sites of various sizes and layouts are being assessed and results will be presented at the Wind Turbine Noise Conference. An updated paper will be available for download after the conference at:
http://www.hayesmckenzie.co.uk/publications.html

4.0 Conclusions

It has been shown for one wind farm site, that the results of the average measured wind farm noise correlated with wind speed differ for two different wind measurement methods. Not much difference has been found for this specific site between using average nacelle anemometer wind speed of all three wind turbines and using the nacelle anemometer wind speed of just the wind turbine closest to the noise measurement location. However, it is expected that for more complex and larger wind farm sites the difference will be more noticeable. A maximum increase of 4 dB of the prevailing wind farm noise at standardised 10 m height wind speeds of 6 and 7 m/s has been found when comparing results with nacelle anemometer derived wind speeds against SoDAR derived wind speeds. However, further investigation will be carried out including other wind farm sizes and wind turbine types to find out whether this result will be repeated.
Furthermore assessments with wind speed derived from the power curve versus wind speed measured at hub height, either from the nacelle anemometer or a stand-alone device, will be included in the presentation and in the final paper published on the Hayes McKenzie website. The effect of measuring wind speed at 10 m height or using standardised 10 m height wind speed on the measured wind farm noise regression curve may also be reviewed.

Disclaimer

It should be noted that the author is not, and does not claim to be, a specialist in meteorology or wind assessment. This paper is a description of observations made during wind farm noise measurements with various means of wind speed derivation.

References

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Updated paper available after the WTN2013 conference:
http://www.hayesmckenzie.co.uk/publications.html