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Constraints imposed by and limitations of IEC 61672 for the measurement of wind farm sound emissions

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Summary

Wind farms are required to comply with noise targets after construction and those same targets are set from a sample of background noise measurements prior to construction. It is not uncommon for predicted and post-construction sound levels from wind farms to show compliance with margins of less than 2dB(A).

With small compliance margins there is a need to consider uncertainties in the instruments taking the measurements. IEC 61672 is a commonly used instrumentation standard for sound level meters to ensure consistent results between different manufacturers. Whilst this and similar older versions of the standard provide some comfort regarding repeatability, they are not necessarily appropriate when trying to push the envelopes of sound level meter use.

This paper details some limitations of the current IEC 61672 sound level meter standard and describes common mal-practice in presentation of sound level data purporting to adhere to this standard.

1 Background to IEC61672

The IEC 61672[1] standard for sound level meters specifies accuracy tolerances from test methods in the time and frequency domain. This standard cancelled and replaced IEC 60804[2] and IEC 60651[3] and is applicable to exponentially averaging sound level meters, integrating sound level meters and integrating-averaging sound level meters.

It is useful to reflect upon the earlier versions of this standard to understand the basic objectives. For example, notes in IEC 60651 with regard to 'Time weighting' explain the historical basis of 'S' (Slow), 'F' (Fast), 'I' (Impulse), and 'P' (Peak) in that these time weightings are based on older instruments. Perhaps more importantly, IEC 60651 notes the following:

> "In the past, frequency weighting and time weighting have been associated with certain characteristics of the ear. However, recent work has not substantiated these historical associations, so that frequency-weighting and time-weighting characteristics of sound level meters may be considered to be conventional. The A-weighting characteristic is now frequently specified for rating sounds irrespective of level and is no longer restricted to low level sounds. Furthermore, standardisation of the I-weighting characteristic does not imply that the relationship between loudness or hearing damage risk of impulsive sounds and the physical characteristics of sounds is thereby precisely presented."

IEC 60651 described the Lin frequency-weighting to be unweighted. This terminology changed in IEC 61672 so that Z weighting became the old Lin weighting and unweighted became referred to as ZERO weighting, all of which are the same.

IEC 61672 states that the standard is for sound level meters that are intended to measure sounds generally in the range of human hearing. Early sound level meters were analogue and had moving coil meter displays and the Impulse response was designed to allow an operator to read the display of a transient short lived sound event having a short rise time. This was achieved with a peak hold circuit with long decay time (1500ms). The 1500ms decay time of the impulse response was never intended to track the rise *and* fall of a sound transient.

Modern fully digital sound level meters can successfully emulate the old analogue sound level meter responses of Slow, Fast and Impulse without the need of a peak hold circuit because the sound level maximum can be digitally stored for later display. However, a 1500ms fall time is still provided to ensure compliance with IEC 61672 when showing a result on the meter's display.

Some modern sound level meters have additional time constants such as 1ms, 10ms or 20ms (eg. Ono-Sokki, Rion, 01dB) and 'short Leq' measurements can be logged. However, these are not specified in IEC 61672.

2 Sound Level Meter Range and Noise floor

The following statements have been made in acoustic assessments using the ETSU-R-97[4] methodology.

> *"Rion NL31 Class 1 noise loggers were used for these measurements. According to the manufacturer's information, the A-weighted inherent internal noise (noise floor) of the Rion NL31 is below 20dB and typically around 17dB."*
>
> *"Noise monitoring was conducted using CESVA SC310 Type 1 octave logging sound analysers, CESVA C250 microphones with PA14 preamplifiers and CESVA TK1000 outdoor microphone assemblies at 1.5m microphone height. The loggers have a low noise floor of typically 16dBA."*
>
> *"Background LA90,10min noise levels range from 17 – 30 dB LA90 at low wind speeds during both night and day times .."*

The last statement was with the use of a Larson Davis 820 Class 1 sound level meter and all recorded data, apart from rain affected results were used in the background regression analysis.

Such statements are commonplace in acoustic assessments and data is included in Sound Pressure Level vs. Wind Speed charts showing data often at the instrument noise floor. The IoA Supplementary Guidance Note 2[7] contains a number of example charts of this type where it is clear that data at or near the instrument noise floor has been included in the data processing.

The IoA Supplemental Note 1[6] expands on the specification of noise measuring equipment described in the IoA Good Practice Guide[5] section 2.4.1 and suggests that the measurement systems should preferably comply with current standards IEC 61672 although earlier standards such as BS EN 60804 may be used to accommodate older instruments. Unfortunately, there is no advice given on the performance requirements of measurement equipment compliant with these standards. It would clearly be inappropriate to use a sound level meter having a noise floor of 40dB(A) to measure background trends, even if it were to comply with IEC 61672.

The Rion NL31 described above indeed has a specification as described, however, the measurement range over which the instrument is compliant with IEC 61672 is only a minimum of 28 dB(A). Similarly, the CESVA SC310 described above is specified to have an electrical noise floor of 15.7 dB(A) but the measurement range to which the instrument is compliant with IEC 61672 and EN 60651 has a lower limit of only 28 dB(A).

The Larson Davis 820 sound level meter has a quoted noise floor of 17.5 dB(A), when used with a 2541 microphone. However, the linearity range for the LD820 is difficult to define since there is a noise floor compensation mode that can extend the linearity by 10 dB[8]. If this mode is not set then the meter reports "Near Noise Floor" when within 10dB of the noise floor as a warning to show potential non-linearity and non-compliance with its standards.

Data presented in wind farm noise assessment reports that are below the lower measurement range of the instrument are not compliant with the specification requirements of IEC 61672. Figure 1 shows the compression effect that sound level meters have as the sound levels approach the instrument noise floor.

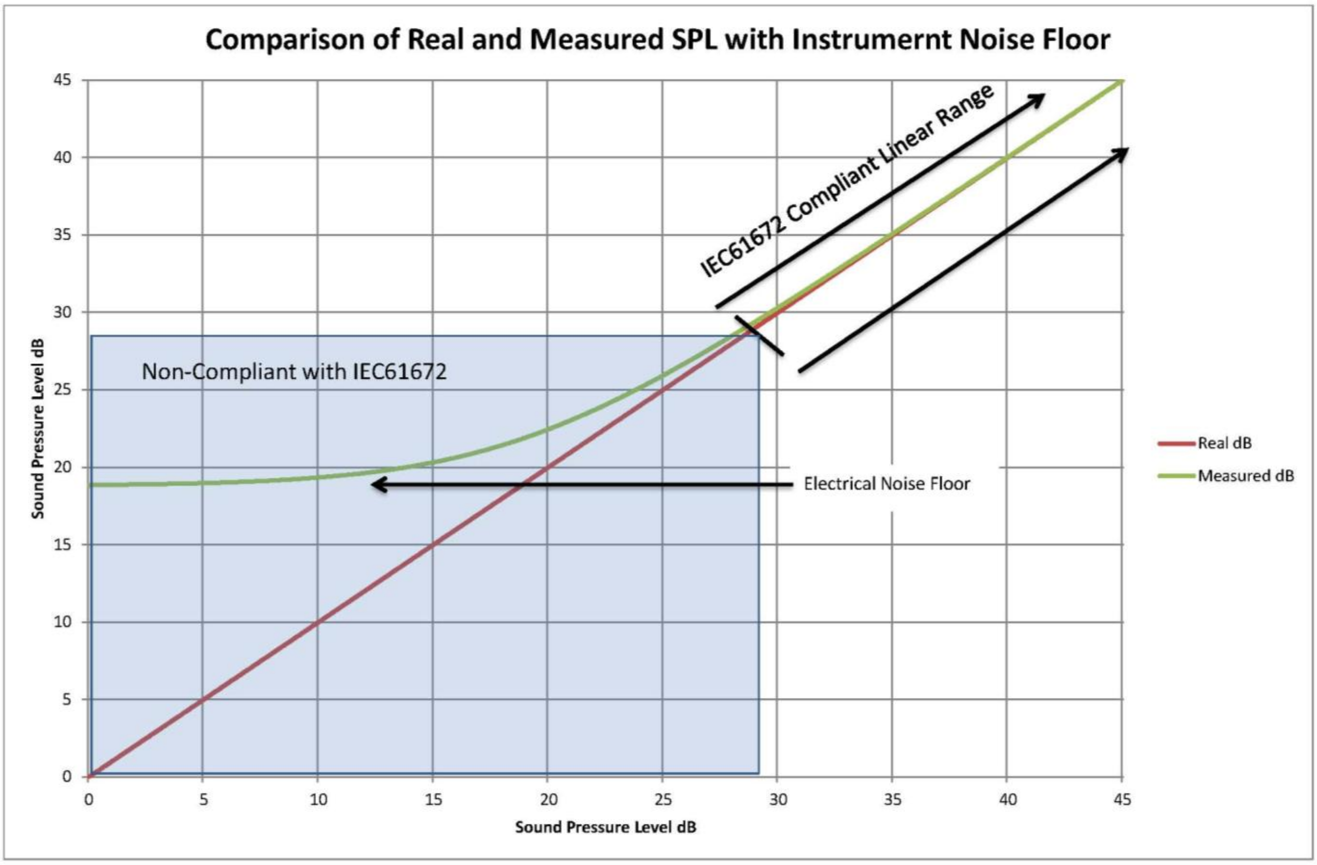

FIGURE 1

The IoA Good Practice Guide suggests that measurement instruments should be compliant with either Type 1 or Class 1 precision. Beyers[9] describes the effective tightening of specifications in IEC 61672 over the years and notes that calibrations to the latest version (2013) may not be successful for previously conforming instruments. This may rule out much of the instrumentation used in past wind farm approvals unless the

Good Practice Guide allows equipment to be used that has compliance with the 2004 version of IEC 61672, for example.

Clearly, any data used between the instrument noise floor and the lower measurement range is non-compliant and should not be used.

The author has yet to see a noise impact assessment for a wind farm where such data has been excluded from the data processing and the derivation of background curves. Furthermore, the absence of guidance in this regard by the IoA working group is a serious failing. Guidance should be provided on the lower measurement range of instruments that are suitable for the task of setting compliance noise curves for wind farms.

The question then arises; how representative are these background curves upon which compliance limits are set? Figure 18 of the Supplemental Guideline Note 2 shows data clearly influenced by the instrument noise floor. In this example, the data limits at around 18 dB(A) and if instrumentation such as the CESVA 310 or Rion NL31 were used to gather this data then the valid data (compliant with IEC 61672) would only be above 28 dB(A).

We then have a situation where many wind farms have been approved using data non-compliant with the IEC 61672 or IEC 60651.

It would be unreasonable to simply delete all data below the lower measurement range of the sound level meter because this would have the effect of artificially raising the background trend curve upon which target noise limits are set. Can this data be corrected in some way?

The method used by Larson Davis to extend the lower linearity is simply to compensate the measured value by the electrical noise floor value. As a sound level meter approaches the electrical/microphone noise floor it starts to report higher sound levels than actual. If the noise floor is 18dB then the artificially higher reported sound level from the meter is (real dB + noise floor dB). So, a simple correction follows where a better reported sound level will result if you take 18 dB from the reading. If the SLM reads 25 dB then the real level would be 25dB - 18dB = 23.95 dB.

Uncertainty increases near to the noise floor of 18 dB; if the measured reading is 19 dB then the real sound pressure level could be 19dB - 18dB = 12dB.

At a reading of 18dB the actual level would be 18dB - 18dB = -∞ and this is where the technique starts to fail. If this type of correction is applied to measured background readings then a conservative result may be obtained for sound levels close to the noise floor of the instrument. Unfortunately, this technique is only applicable to short Leq data, not statistical data such as the $L_{AF90,10min}$. Mathematically, it is impossible to correct an $L_{AF90,10min}$ in this way unless each short L_{Aeq} that forms the statistic is individually corrected. If the method is applied to the $L_{AF90,10min}$ it is not considered rigorous.

The chart in Figure 2 provides an example of such a crude correction on data taken with a CESVA 310 sound level meter. The corrected data is shown as 'Extended LA90'. A simplistic trend analysis is shown in accordance with the IoA Good Practice Guide Supplementary Guidance Note 2.

A ‘Flat Lined Background Noise Level’[7] at lower wind speeds would be approximately 3dB higher with uncorrected data. Different measurement data can show a larger discrepancy than 3dB.

Wind farm noise assessments often have very small compliance margins. In such cases the effects of non-linear data become important.

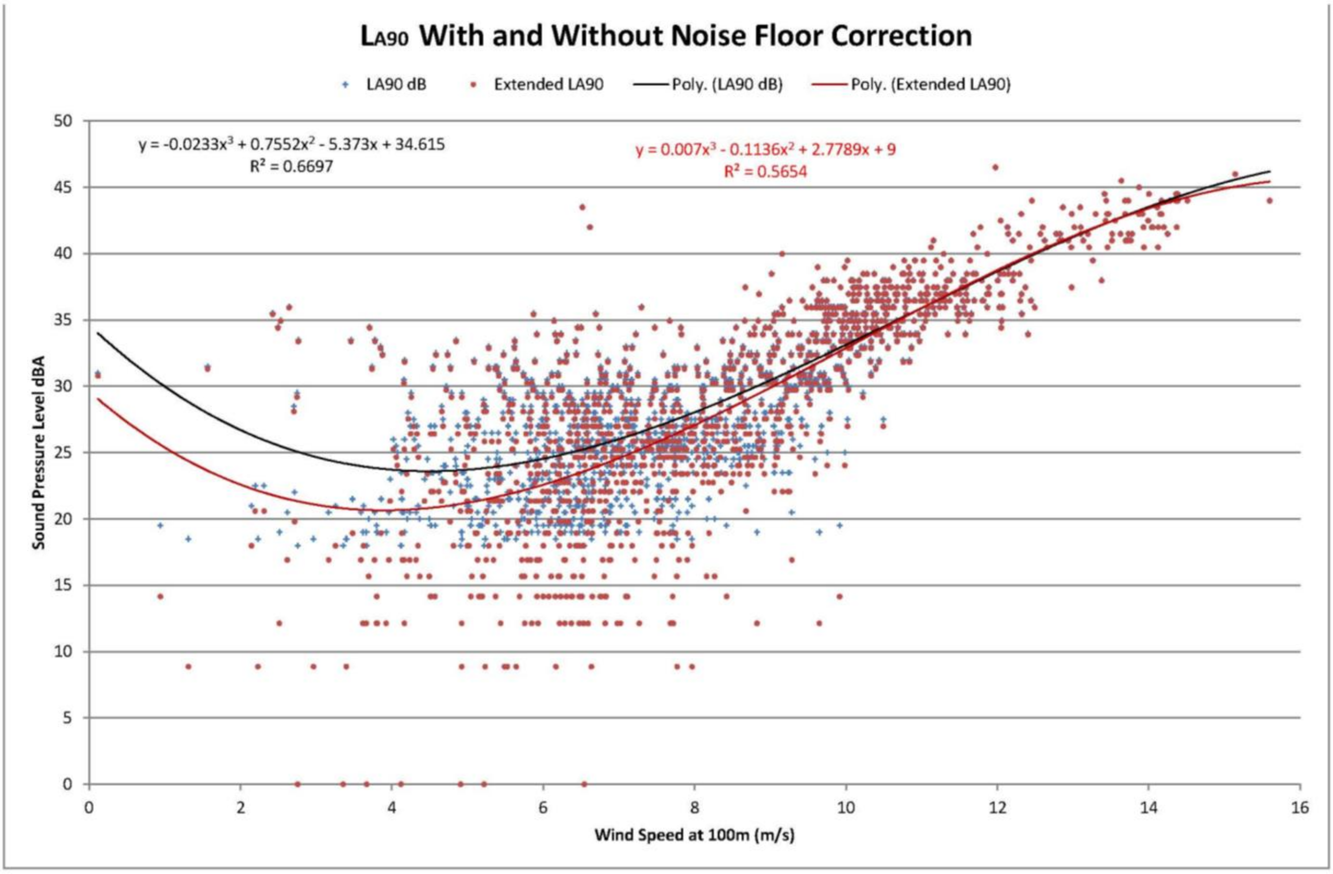

FIGURE 2

2.1 Use of different instruments in assessments

It is often the case that compliance assessments of wind farms take place many years after original background measurements have been taken and sometimes by different companies.

If instrumentation having a higher noise floor is used to determine a background trend line, upon which wind farm noise targets are set, is then replaced by different instrumentation having a much lower noise floor for the compliance assessment, we have the very real potential to demonstrate from the results that the ambient noise in an area falls after the wind farm is built.

This strange effect is observed in a number of charts produced for compliance assessment reports that the author has seen. For example, a number of charts seen in compliance reports show the electrical noise floor of the instrumentation used to determine the background trend line at 26dB(A), yet a different sound level meter was used by a different organisation for compliance assessment that had a noise floor of 17dB(A). Notwithstanding that the original data used to determine the background trend line was non-compliant with IEC 61672 in the non-linear range from 26 dB(A) to about 32 dB(A), the data was used to demonstrate compliance. In the wind speed range just after turbine cut-in it appears that the post construction trend line is lower than the background trend. It would be a strange conclusion to draw that the construction and operation of the wind farm is reducing ambient noise in an area.

Again, this is a issue that the IoA Guidelines do not address. Simply referencing IEC 61672 without further qualification is not good practice.

3 Infrasound

Sound level meters conforming to IEC61672 have regularly been used in wind farm studies of infrasound[15,16,17] immissions. Often, one-third octave band analysis data is reported below 10Hz, yet, IEC61672 specifies frequency weighting tolerances only down to 10Hz. At 10Hz, for example, the acceptable tolerance on reported sound pressure level is +3dB to minus infinity.

Compliance with IEC61672 does not provide any assurance of accuracy below 10Hz. This fact was realized by Schomer[12] in the Shirley wind farm study who stated that:

> "A-weighting is totally inadequate and inappropriate for description of this infrasound. In point of fact, the A-weighting, and also the C and Z-weightings for a Type 1 sound level meter have a lower tolerance limit of 4.5 dB in the 16 Hz one-third-octave band, a tolerance of minus infinity in the 12.5 Hz and 10 Hz one-third-octave bands, and are totally undefined below the 10 Hz one-third-octave band. Thus, the International Electrotechnical Commission (IEC) standard needs to include both infrasonic measurements and a standard for the instrument by which they are measured."

ISO 7196[10] describes the G-weighting filter. Unfortunately, this standard does not provide acceptable tolerance limits and refers back to detectors having characteristics no less stringent that those specified for Type 1 sound level meters having the F or S time-weighting characteristics of IEC 61672. However, measurements of wind farm emissions[13, 14] below 20Hz show that the G-weighting filter does not encompass the frequency range of emissions that contain the majority of wind farm generated infrasound, which generally is below 6Hz. The G-weighting is unresponsive to and is unrepresentative of wind farm infrasound emissions.

An example of the challenges posed in taking infrasound measurements using different sound level meter models from the same manufacturer, each having compliance with IEC 61672 is described by Cooper[13].

There are limitations to any IEC 61672 compliant system that uses a microphone to quantify pressure variations in the low infrasound region. For example, one of the best infrasound microphones, the GRAS 40AN, attenuates pressure variations at 0.1 Hz by approximately 9 dB, and more so at lower frequencies. Another microphone example is the GRAS 40AZ that has a 25 dB sensitivity reduction at 0.1 Hz. Furthermore, the phase response changes significantly as the high pass filter knee (-3dB point) is approached.

Changing phase response characteristics can alter the pressure waveform significantly and lead to incorrect estimates of peak pressures. In contrast, a microbarometer can measure absolute pressure. These devices are often high-pass filtered around 0.05 Hz to increase sensitivity by reducing the effects of weather pattern changes and atmospheric turbulence. Microbarometer based instrumentation should have regard to ISO 10843[11] to keep phase distortion to less than +/- 10 degrees, something not considered in IEC 61672.

3.1 Zero weighting dB(Z)

The dB(Z) or ZERO weighted response described in IEC 61672 is generally not well understood. A dB(Z) value from a sound level meter compliant with IEC 61672 can produce a totally different dB(Z) value from another IEC 61672 compliant sound level meter for the same input signal.

The dB(Z) values recorded by different sound level meters simply mean a decibel sound pressure result that is the best that that particular sound level meter can achieve without any weighting applied. Because the tolerance at 10Hz in IEC 61672 is +3dB to minus infinity, two sound level meters measuring sound levels containing a significant amount of sound energy around 10Hz can produce results differing within the full dynamic range of either instrument.

Infrasound emissions from wind farms can produce wildly different results using the dB(Z) parameter in different sound level meters that are compliant with IEC 61672. It is therefore unwise to compare reports having dB(Z) data recorded with different instruments.

4 Time Constants and Amplitude Modulation

Methods of assessing amplitude modulation (AM) from wind turbines are currently being reviewed. A common requirement is to track the rise and fall of sound level to quantify the amount of AM.

Some of the AM assessment methods being considered are based upon the amplitude variation of A-weighted sound levels with time. Older analogue sound level meters would output a voltage that was proportional to the dB sound pressure level to a chart recorder to record AM. This signal would be the output from the DC connector of the sound level meter.

Modern IEC 61672 compliant digital sound level meters have the ability to store sound level data at different rates into memory for later download to a computer that can then prepare a printed chart. Sound levels stored in the memory of sound level meter loggers are sampled at varying rates. A modern digital logging meter can often vary the storage sampling period, yet there is no standardisation between different sound level meter models from different or even the same manufacturer. The storage sample rates can vary from 1ms through seconds to many minutes.

Older analogue sound level meters ‘stored’ sound level variations with the use of external chart recorders. The chart recorders could change the pen response and data from the sound level meter was often obtained directly after the rms detector prior to any time weighting circuit. The time weighting was determined from the pen speed in the chart recorder.

The ability to drive external chart recorders is still an option on modern digital sound level meters where AC and DC outputs are provided, however, there is a wide variation on the signal that is observed from the DC out connector. For example, Larson Davis 700 and 800 series sound level meters are part analogue and part digital. The analogue part provides the same functionality as the earlier fully analogue meters that had moving coil needle displays. The digital part of these meters simply stored the sampled analogue dB voltage levels to provide Ln statistics and Leq values. The DC output from the 700 and 800 series sound level meters provide a voltage level proportional to dB before the time weighting circuitry. The DC output response was therefore faster than that required to address the rise time specification for Impulse response and is independent of the time weightings of Fast, Slow or Impulse.

The latest fully digital sound level meters from Larson Davis have a voltage level proportional to the dB sound level at the DC out connector, but the signal is pre-conditioned to have time weighting limited to the options of Fast, Slow and Impulse. IEC 61672 does not standardise the type of output signal available at the AC or DC output connectors. The AC output also suffers from this lack of standardisation. For example, some sound level meters have AC outputs that reflect the frequency weighted signal after the microphone preamplifier. Others pass the signal from the preamplifier through a power-amplifier to drive headphones that introduces a non-linear frequency response or dynamic range change that may result in non-compliance with IEC 61672 specified limits. However, the meter may still comply with IEC 61672 test requirements.

A manual method of assessing amplitude modulation from an A-weighted chart trace has been developed for use in a wind farm planning approval condition in the UK (Den Brook Condition)[18]. An automated method has been proposed by RES[19] to emulate the manual method. However, the RES automated method has been shown to be deficient[20, 21] in this regard. The basic approach in the Den Brook amplitude modulation assessment method is to sample the A-weighted sound level outside a dwelling using Fast time weighting response at a sample rate of 125 ms.

IEC 61672 defines the rise time (exponential time constant) of Fast response to be 125ms. However, the fall time of Fast response is defined to be ‘at least 25 dB per second’. The ability of a sound level meter to track the fall of sound level is important in quantifying the trough of the AM time signal. Obviously, sound level meters having a faster fall time can track the trough of an A-weighted sound level more accurately and different sound level meters compliant with IEC 61672 can produce different AM values if they have different fall times.

IEC 61672 shows the expected difference, $ƌ_{ref}$, in L_{AFmax} to L_A for 4kHz tone bursts having different durations. For example, the measured L_{AFmax} for a 100ms tone burst is 2.6 dB lower than the actual L_A value of the tone burst with IEC 61672 specifying an allowable uncertainty of +/- 1.3 dB. An equation is provided to estimate $ƌ_{ref}$ for different time constants, as follows

$$ƌ_{ref} = 10 \lg (1 - e^{(-Tb / t)})$$

Where Tb is the tone burst duration and t is the exponential time constant.

For Fast response, t = 125ms. If a response time of 1ms or 10ms is used, then, for a 100ms tone burst, $ƌ_{ref} = 0$ and for a response time of 100ms and 100ms tone burst, $ƌ_{ref} = 2$.

AM does not generally have a sinusoidal pattern and can have dips within each modulation. Time traces of A-weighted sound levels exhibiting AM from wind turbines can be very complex. When there are multiple turbines the AM patterns are even more complicated. Figure 3 shows a 72-sec time trace 700m from two MM82 wind turbines.

Research from the University of Salford[23] has concluded that “Faster modulation increased annoyance rating” but tests were not completed on the rates of change of modulation typical of the sample shown in figure 3. The team also concluded that there were no clear effects with changing pulse shape in their tests. However, the tests were based on synthesised sounds having constant modulation envelopes.

The AM repetition at the start of the time trace in figure 3 is around 2 Hz but AM peaks can be separated by <1ms to 1.2s (blade pass frequency) as the phase between the rotors change. In such circumstances a Fast response may greatly underestimate the real magnitude of AM.

A better method of tracking the real AM would be to use short Leq values that are available from many modern integrating sound level meters. Alternatively, sample the output from the DC connector if the output is derived directly after the rms detector, before any slower time constant is applied (eg. Larson Davis 700 and 800 series meters).

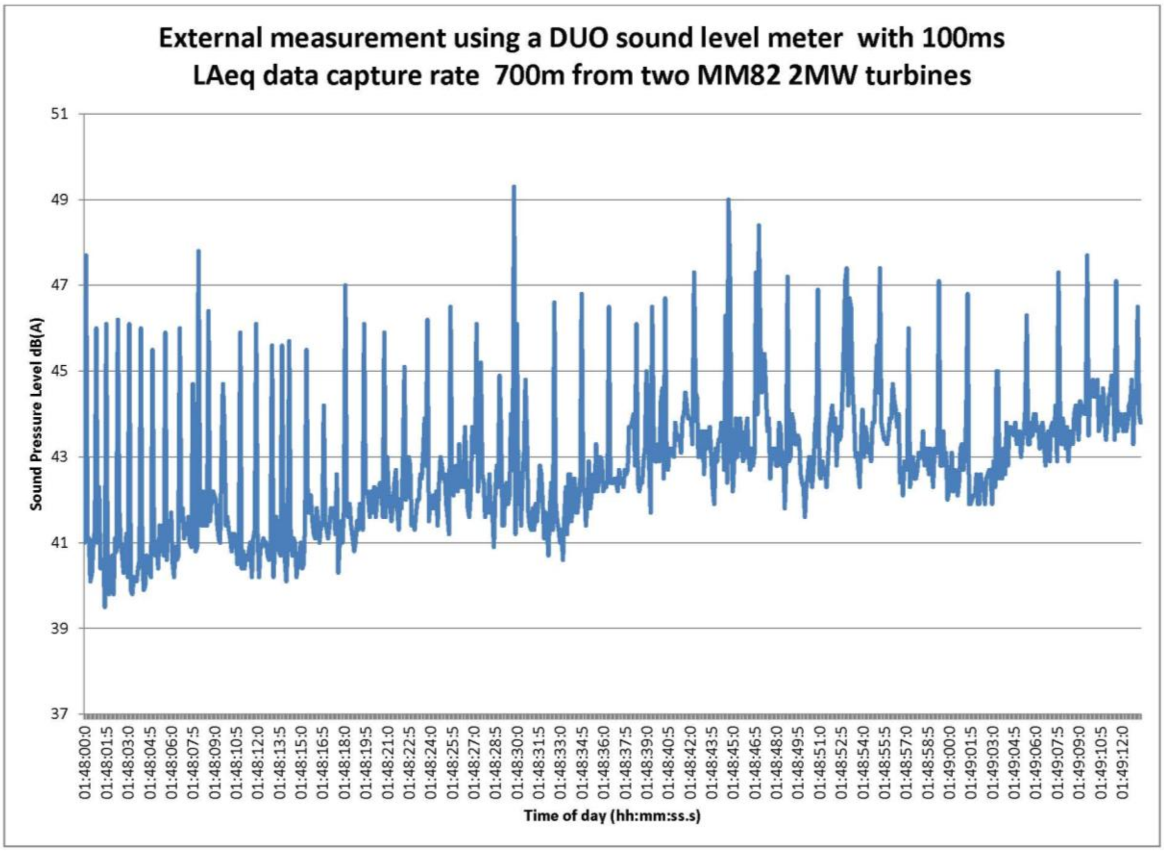

FIGURE 3

The Fast time weighting is conventional and does not reflect the capabilities of the human ear. Oberfield[22] describes the results of two experiments assessing the perceived loudness of multiple 100ms wide-band noise segments. The results suggest two independent mechanisms, one being the primacy/recency weighting pattern of the sound segments. Thus, AM perception may not simply be a function of modulation depth, but can depend upon onset / decay rates and modulation frequency (as also reported by Salford University[23]).

Future AM investigations should not be limited by the Fast response sampled at, say, 100ms. Greater resolution of the amplitude time history, than can be afforded using the Fast response, would be beneficial in future AM research to better resolve the detail in AM and to minimise amplitude uncertainty.

5 Conclusions

IEC 61672 specifies acceptable performance tolerances for sound level meters used generally in the audible frequency range and it is referenced by the IoA Noise Working Group[6] as a standard to meet for the 'good practice' measurement of sound from wind turbines. The reference to IEC 61672 is simply made without qualification, except for the Class of instrument.

The author is aware of numerous wind farm assessments, made in accordance with the ETSU-R-97 methodology, where data has been used in preparing trend lines from background and post-construction operating conditions that is outside the range of measurement for which the sound level monitoring equipment is compliant with IEC 61672. Such charts are presented as examples of good practice in the IoA Good Practice Guide. The author knows of no ETSU-R-97 type assessment where account has been made for such non-compliant data that is outside the measurement range of the instruments. The IoA Supplemental Guideline Note 1 'Data Collection'[6] needs to be amended to address these issues.

A correction methodology to extend the noise floor of instruments has been presented; however, this method would not be compliant with IEC 61672 and is not rigorous.

It is recognised that the time and frequency weightings described in IEC 61672 are conventional and do not represent the characteristics of the human ear. The IoA Good Practice Guide[5] and its supplementary Notes should provide guidance on appropriate time constants and short Leq sample rates that better define emissions from wind turbines.

Guidance is required on the temporal weighting of the loudness of time-varying sounds as it relates to amplitude modulation and the uncertainty associated with different short Leq sample rates to better define amplitude peak and trough determinations (AM).
It is recommended that future research into AM record time histories utilising currently available sound level meters with sample rates of around 10ms as short Leq (not time weighted with Fast response). Such equipment is also compliant with IEC 61672.

Z-weighting can provide large differences in readings between different sound level meters if the source contains infrasound typically found in wind turbine noise emissions at frequencies below 6 Hz. It would be a mistake to assume that dB(Z) results are accurate because there is compliance with IEC 61672.

IEC 61672 currently does not include the standardisation of instruments suitable for the measurement of infrasound. Such a standard would prove useful considering the amount of planned research in this area.

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