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Cotton Farm Wind Farm – Long term community noise monitoring project – 2 years on.

Mike Stigwood, MAS Environmental, UK
Sarah Large, MAS Environmental, UK
Duncan Stigwood, MAS Environmental, UK

Abstract

In 2013 MAS Environmental established a permanent monitoring station to record and publish data online, located 600m from the nearest turbine, to correlate the impact upon the community and provide an extensive database. This database enables a wider study of the effect of a number of variables in the noise immission on the communities affected. The database has enabled testing of proposed controls, particularly in relation to audible amplitude modulation. Previous papers in 2014 on this project have described its background and the early results of the data collected, especially in relation to the occurrence of the special characteristic amplitude modulation.

This paper includes further evaluation of the now extensive database collected over nearly 2 years and how noise features correlate with community response / complaints, including analysis of some of the prominent characteristics recognized as a feature of the community noise as created by this wind farm and how they impact.

The data has also been used to test the appropriateness and reliability both of some commonly applied and also emerging principles and methods for Amplitude Modulation (AM) noise control used for wind farms. It identifies issues relating to uncertainty, error and reliability / repeatability. In this paper particular focus is placed on the analysis of automated or semi-automated Fast Fourier Transform procedures and whether they can adequately detect and quantify AM. This part of the long term

study focuses on the parameters and procedures used to identify AM noise. Analysis of the inability of noise controls to reflect true impact in relation to Cotton Farm wind Farm data is also explored.

1. Introduction

The Cotton Farm Wind Farm community noise monitoring project is approaching two years and provides real time sound and weather data at a representative community location. It includes on-line information for anyone to evaluate and improve their understanding of wind farm noise.

This paper is intended to be one in a series of data findings. Some significant findings previously reported are summarised with additional analysis of analytical techniques which look at the special characteristic, Amplitude Modulation.

Web link to the Cotton Farm WF data: **www.masenv.co.uk/~remote_data/**

1.1 Cotton Farm Wind Farm and its locality.

Cotton Farm WF comprises 8 Senvion (formerly REpower) MM92 2.05MW turbines with a total capacity of 16.4MW located in Cambridgeshire UK. The nearest dwellings are approximately 600 metres away. The permanent monitoring station was established on the outskirts of Graveley. We have now collected over 22 months sound, audio and meteorological data. Sound data recorded includes100ms LAeq, and 1/3rd octave data, 10 minute average values and statistical parameters. Audio is also recorded for post processing and source identification. Further information can be found on the web link or in previous papers.

2. Summary of previous findings.

The Cotton Farm project compliments measurements made by MAS Environmental (MAS) of amplitude modulation (AM) and other elements of wind farm noise at over 18 sites across the UK. Previous findings from the Cotton Farm project were reported at Internoise 2014 and further information on the details of the project is set out in that paper. The early research focused on:

> AM occurrence with a modulation depth in excess of 5dBA
> Whether theories proposed by ReUK on AM occurrence were well founded
> ISO9613-2 prediction methods using the IoA Good Practice Guide

2.1 AM occurrence.

During a 10 month period 54% of nights were significantly affected by periods of AM with modulation depth of +5dBA. A focused study of 2 months of data found:

82% of nights MD+5dBA (46 nights)
30% nights classed severe AM (17 nights)
10% nights classed borderline MD+5dBA (6 nights)
18% nights little or no MD+5dBA (10 nights)
4 continuous nights of severe MD+5dBA[1]

AM was found to occur under upwind conditions (easterly) for a higher proportion of the time compared to downwind, except at higher wind speeds. At 600m distance decibel levels recorded during AM incidence were of similar magnitude when upwind and downwind.

The Cotton Farm exercise indicates directionality patterns to AM that fits reasonably with the theory of Lee et al (5) for convective amplification (Doppler shift). Modulation depths in excess of 5dBA and up to 15dBA were common in the far field. There were prolonged periods of persistent and consistent AM, spectral content and directionality patterns and notably the absence of AM directly downwind of a turbine. These are inconsistent with the ReUK theories on blade stall. Changes to AM level arising from blade pitch changes are consistent with the occurrence of directionality patterns.

Laboratory tests comparing response to increasing AM LAeq by increasing the signal energy level do not replicate or reflect the field impact when LAeq increases. Complaints appear to relate more to the audibility of specific intrusive characteristics and not its average energy level.

Turbine switch off tests enabled comparison with the immediate change in the soundscape. This showed that impact during periods of AM is a cumulative effect of both the AM and the spectrally different steady WTN that partly masks AM. Steady WTN presents a stepwise increase typically 9dBA masking the normal soundscape with an alien spectrum and AM is superimposed upon it. There are two distinct noises which impact in combination increasing noisiness and are ideal for reproducing impact to test subjects in a laboratory, rather than artificially raising sound energy levels. Noise character varied upwind and downwind.

Increases above background noise levels exceed predicted levels and contradict predicted occurrence in ETSU-R-97. Analysis of the real time sound energy change during switch off tests better describes impact. The addition of a 5dBA penalty to ETSU-R-97 derived limits fail to curtail adverse impact from AM. Conversely methods

[1] Note the background noise level during this period and as influenced by the wind farm noise was 31dB L_{A90}(10 minutes) and modulation peaks were up to 50dBA.

adopting the D_{AM} metric could be effective if not linked to a penalty approach.

2.2 ISO9613-2 prediction methods using the IoA Good Practice Guide

Procedures adopted in the UK to predict wind farm noise for flat sites are shown to understate decibel levels at far field locations at lower hub height wind speeds. Long term Cotton Farm WTN measurements compared to predictions are presented in Figure 1 below.[2] Compare the purple predicted level for the turbines actually installed with the grey circles showing wind farm noise and the green line showing the average wind farm noise for a standardised wind speed. The values indicate average levels were typically 3-4 dBA higher than those predicted and during periods of worst impact levels were of the order of 5-9dBA higher than predicted. More than 85% of the calculated wind farm noise levels exceeded the predicted values.[3]

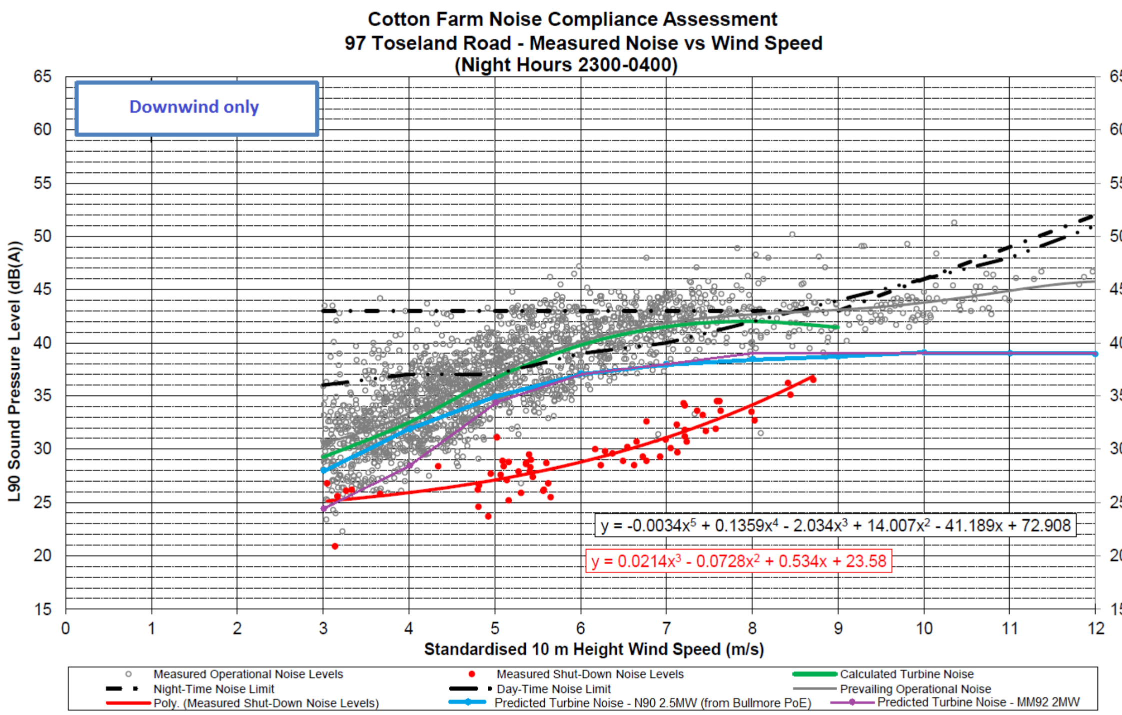

Figure 1: Compliance measurements at Cotton Farm Wind Farm - predicted turbine LA90 v actual turbine LA90

These understated prediction findings are also supported by other data including from the Swaffham II turbine. In that case predictions understated levels by on average 5.7dBA. Similar exceedances have been found by others (11).

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[2] The measurements reported in this section were obtained independently from the operator's acousticians to avoid any dispute as to the findings based on 10m height wind measurements and they relate to standardised wind speeds.

[3] After deducting background noise contribution.

3. Assessment and comparison of excess amplitude modulation methods

MAS are using the Cotton Farm data in cooperation with a UK based Independent Noise Working Group (INWG) where specialists in physics, acoustics, health, meteorology engineering and law are working together on the development of workable control mechanisms that protect communities from adverse impact caused by special noise characteristics and especially excess amplitude modulation. Full results of the groups first stage of study are due to be reported in the first half of 2015.

The work includes the review of assessment methodologies including those adopting Fast Fourier Transform (FFT) based algorithms.

3.1 Fast Fourier Transform (FFT) methods of data processing and analysis.

Various algorithms have been proposed by others to analyse wind farm noise data with the objectives of facilitating identification of EAM and automating assessment of impact. Some of the aims of the methods developed include:

- → Excluding extraneous noise from being counted as wind turbine noise.
- → Identifying peaks of noise that can be attributed to the rotation of the blades and occurring at blade passing frequency.
- → Rating the noise according to its intrusiveness.

MAS and the INWG have used the Cotton Farm data in conjunction with data from other sites to evaluate how well various procedures and algorithms work in identifying and rating AM whilst excluding extraneous noise. We have compared various procedures to see how well they define and determine amplitude modulation occurrence as well as its corresponding impact. This includes the procedure developed by Renewables UK (ReUK)[4] as reported in December 2013 which is reliant on FFT[5] and a subsequent methodology developed by RES[6] in relation to the Den Brook wind farm, which has a separate empirical test[7]. Further details of the RES method are available on the West Devon DC planning portal website. Another well developed procedure is detailed in Fukushima etc al (2013) and has also been tested with the Cotton Farm data. The method determines a DAM (AM depth) rating

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[4] Renewables UK is the wind industry's representative body in the UK.

[5] A number of methods have been developed using the Fast Fourier Transfer approach, potentially with the hope of automating data analysis.

[6] Renewable Energy Systems – A wind farm developer who are developing the Den Brook site.

[7] The RES empirical procedure is intended to reflect or trigger investigation only in those circumstances when the Den Brook metric is triggered by wind turbine noise. Criticism was made of the Den Brook metric on an erroneous basis it was triggered by other environmental noise.

by comparing the differences in the historical "fast" and "slow" processing meter settings of 125ms and 1 second respectively. This procedure is not reliant on the use of FFT. Finally the Cotton Farm data has been tested using the principles of BS4142. In the UK British Standard 4142, which is used for industrial noise, was extensively updated and improved in November 2014. Use of BS4142:1990 was rejected by the authors of ETSU-R-97[8], asserting issues relating to limitations within its procedures. Those limitations do not arise with the current 2014 version and its guidance is compared in this paper to assess how it rates wind farm noise against those other procedures.

3.2 Discussion on the approaches to the assessment of special characteristics

It has long been recognised that impact from sound of the same decibel level can be substantially different depending on its characteristics and whether it is considered subjectively pleasant or unpleasant.[9]

Two separate approaches to assessing wind farm noise characteristics appear to be emerging from research. Some appear to seek to develop algorithms that can process large amounts of noise measurement data, exclude periods either contaminated with significant extraneous noise or which do not include sufficient levels of amplitude modulation to warrant control and ultimately provide a judgement of acceptability. Currently in the UK tonality is normally, but not always, addressed as part of any noise limits developed using ETSU-R-97.

Other approaches aim to simply provide a measure of AM by varying means of assessment. This may be a measure of peak to trough level, as proposed in the original Den Brook EAM condition, or the DAM rating level identified above. External to the UK the method of determining special characteristics is not necessarily defined. Alternative approaches consider impulse content and onset rate of noise. This paper focuses on a limited range of comparisons out of necessity.

These 'other' approaches assume that the noise data being interrogated is a true reflection of the noise source that is complained of. Measured data is first filtered using simplified analysis techniques in order to exclude unsuitable data and select relevant periods for further analysis. This approach follows the traditional methods developed and applied without difficulty for decades. It has significant advantages which are considered in more detail below. This approach is in direct opposition to that of the ReUK method, which prescribes data analysis first and data checks, such as audio inspection, second.

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8 This is the UK Government's preferred method for assessing wind farm noise.

9 See for example the introduction to BS8233 2014 and paragraph 7.7.1 which discusses different tolerance of noise with and without character.

The primary objective of many methods used to assess special characteristics in noise, such as excess amplitude modulation, appears to seek application of a penalty to the average 90th percentile noise limit level (LA90). This is the approach proposed by the ReUK AM condition. Our findings on this were presented at Internoise 2014 and found that 90th percentile values were commonly lower when special characteristics (EAM) occurred and as a consequence the penalty approach failed to prevent any intrusive noise impact. The addition of penalties did not lead to the wind farm noise levels breaching their limits.

3.3 Comparative table of procedures

The table below provides an outline comparison of the methodologies outlined above. I have termed these 'FFT filtering'[10] and 'assessor filtering'. The concept of the two FFT procedures appears to be to try to develop an efficient algorithm to automate the analysis of large quantities of data and so exclude the need for assessors to spend many hours evaluating possible AM occurrence. Thus, it is intended to operate as a filter mechanism leaving a smaller dataset for closer scrutiny and checking against audio. This subset is then quantified. The FFT procedures rely on use of the turbine SCADA[11] data to apply a blade passing frequency (BPF). In order to speed up this part of the process we have automated a range of methods for determining the BPF. This has the added advantage of comparing different averaged BPFs to assess the affect on the method.

The two other methods considered, D_{AM} and Den Brook, require the assessor to pre-assess which datasets include AM using alternative procedures and then quantify the AM. These pre-assessment methods include:

→ Selecting periods identified by the noise receptors as affected
→ Selecting periods indicated by the meteorological conditions
→ Visual checking of temporal dBA graphs for recognisable patterns
→ Visual checking 1/3rd octave temporal data to deselect non-turbine sources
→ Use of FFT procedures as a cross-check
→ Audio checking of finally selected periods where any doubt arises.

The quantification process needs to enable an assessment of the frequency of occurrence of AM, the times when AM occurs and its duration. It is important therefore that any process has a low failure rate (i.e. that it correctly identifies all periods of EAM and correctly excludes periods not affected by EAM). Another

[10] The method is defined in the ReUK study see Reference 2.
[11] Supervisory Control and Data Acquisition

obvious issue is the time required to apply each method of filtering data. 'Assessor filtering' methods, such as Den Brook and D_{AM}, require primary checks to ensure it is turbine AM and then a secondary assessment of impact. The ReUK and RES approaches, 'FFT filtering', requires a primary data processing step using an algorithm based filter and a secondary post processing check to ensure that the data is turbine AM and assuming that the filter has correctly identified and excluded relevant periods.

A summary of the four main methods identified above and the steps involved in using each method is illustrated in figure 2. The figure provides a brief summary of the basic steps, the actual RES and RUK methodologies provide more detail and specific data processing methods to achieve these steps.

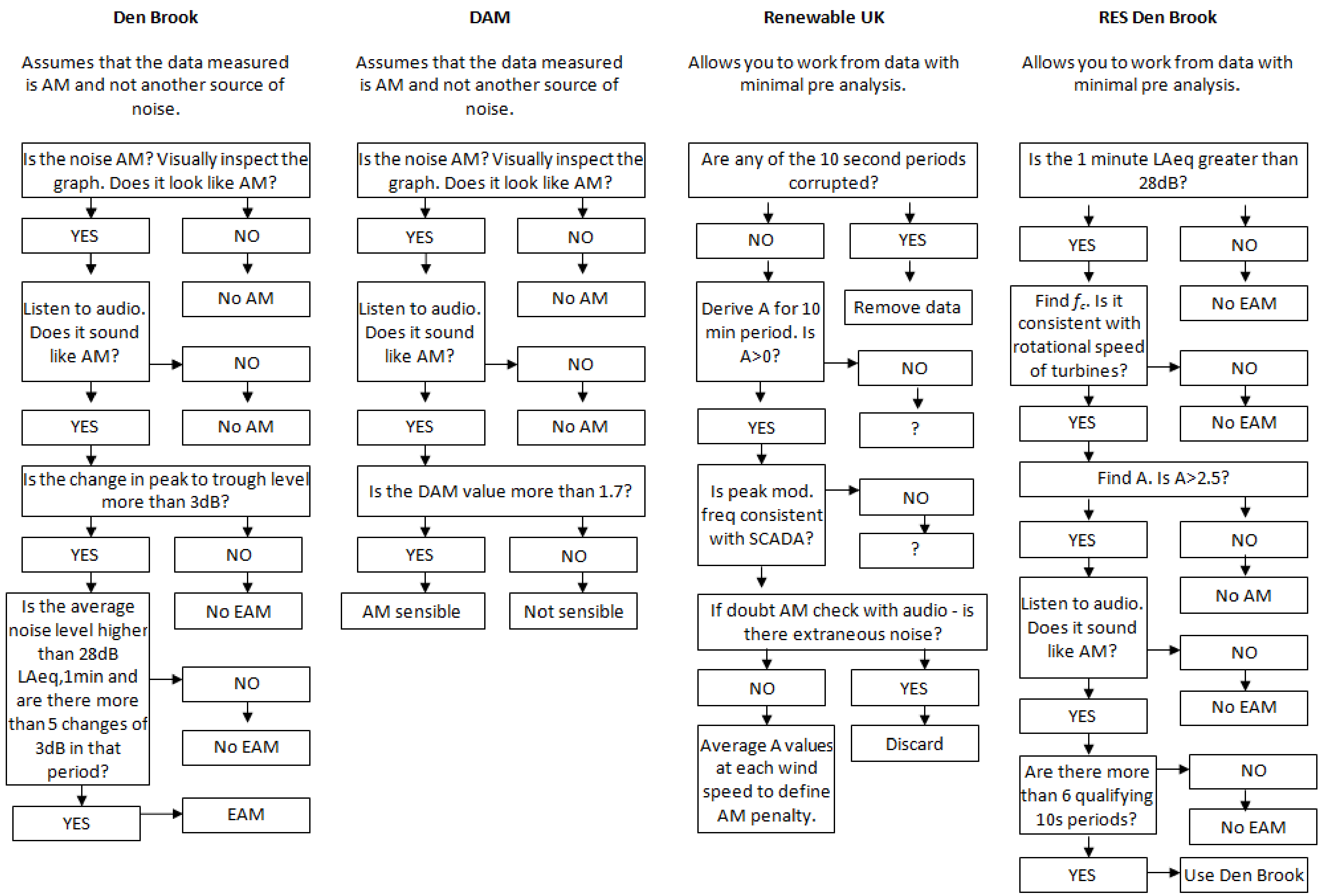

Figure 2 : Comparison of methodology for each AM method assessed

The D_{AM} and Den Brook methods require the least number of steps to achieve an AM value / assessment result. The RES method has the most steps. Whilst there are clear steps in each method the processes that achieve these steps are vague and not clearly defined. This could lead to differences in the results gained from the same method.

The Den Brook, and presumably the D_{AM} method, require confirmation that the data is AM and is generated by the wind turbine / wind farm. This is not specifically defined in either method, but is presumed logical in implementing these methods as with any other noise condition as implemented in the UK. The steps set out above are commonly used.

The first step in the ReUK method is also to remove corrupted data; however, it is unclear what constitutes 'corrupted data' or indeed how this is decided. For example, 'corrupted' may simply relate to the removal of rain affected periods, as is the case with ETSU-R-97 assessment. 'Corrupt' could also convey the need to remove extraneous noise, as with the Den Brook and D_{AM} methods. However, the ReUK methods clearly aims to minimise human judgement, i.e. time spent looking at the graphs or listening to the audio, and so it seems unlikely and illogical to visually or audibly review the data at this stage. If so the method would serve no benefit over the Den Brook or D_{AM} method and the audio check specified later in the ReUK method would be redundant.

An issue in clarity arising with both the RES and ReUK methods is the check for consistency with the blade pass frequency (rotational speed of the turbines) or SCADA data. There is no definition of consistent, how often consistency checks should be made and how such judgements should be made. Where turbines have variable rotational speeds or where multiple turbines might cause variation in the blade pass frequency there could be differences between what is and isn't considered consistent. Checks using a simple parameter range, for example +/- 10%, might still require significant human input, which again defeats the benefit of an automated process. The +/-10% rule also allows more leeway for inconsistency where turbines have a higher rotational speed than those with a lower rotational speed.

4. Results

4.1 Findings on the comparative testing for the identification of AM.

The manipulation of the data, i.e. how the resulting value is derived from the raw data set, is not always clear in the ReUK and RES methods. The AM values that arise from these methods do not well relate to the peak to trough level of the turbine noise. AM values arising from the D_{AM} method also do not reflect peak to trough variation in many cases.

The FFT methods cannot deal with all the variables that manifest in real word data and present serious problems in the filtering of data. These methods only worked in very specific circumstances such as a clean AM trace that is not corrupted by extraneous noise or multiple turbine traces. Successful analysis with these methods requires regularly occurring AM and even when this is true the methods can include extraneous noise. Ambiguity and difficulty over the method of determining BPF can dramatically change the outcome even with data that should provide a clear finding of EAM.

When taking the worst case recorded noise impact from the Cotton Farm data the ReUK method does not provide any control. Taking a period of AM with high sound energy, modulation depths of typically 4-7dBA but up to 15dBA occur at times and erratic noise with a range of annoying characteristics, the method only applied a penalty of 3.3dB. As the LA90 noise was more than 3.3dB below the ETSU-R-97 derived limit it permitted what was subjectively considered the most intrusive noise identified from Cotton Farm WF.

The FFT filtering method proved to be relatively time consuming both in preparing and processing the data. Because of the method's high failure rate it was necessary to re-run the assessor filters, such as listening to audio data, in any event and thus was laborious and problematic. Even where the additional assessor filters were not applied and it was assumed the algorithms were efficient, the process was substantially more time consuming than first applying the assessor checks.[12]

The FFT procedures are helpful for determining BPF of the particular intrusive noise when arising from a single turbine within a wind farm, sometimes when there is a second contributing turbine or if wind farm noise (i.e. from multiple turbines) is well synchronised. However, in many cases the BPF derived from the noise data is unlikely to be consistent with the SCADA BPF due to variations between turbines, the SCADA averaging period and as there is the inability to address temporal variations. The purpose of the blade passing frequency test is to help determine the source of noise but reliance on it for automated detection of AM may potentially exclude significant periods of WT AM.

Both the ReUK and RES procedures have significant potential failure rates. The RES method is subject to false positives. It identified EAM where there is none, includes extraneous noise AM and also misses periods of AM that are consistently near its trigger boundary.

It is difficult to envisage a fully automated process which accurately assesses

[12] Assessor checks require limited training to be able to recognise AM patterns and within a short period of typically about 20 minutes it is possible to check a day of data for further analysis using temporal graphs with 2 minutes data per page.

AM. The RES and RUK methods aim to characterise AM by approximating the AM variation as a regular sine wave, but AM rarely approximates a sine wave and typically occurs within what is essentially a random signal. As such there will always be the need to listen to the data to verify AM and automation can only really work where there is no other corrupting noise.

4.2 Illustrative examples of failure of some proposed controls.

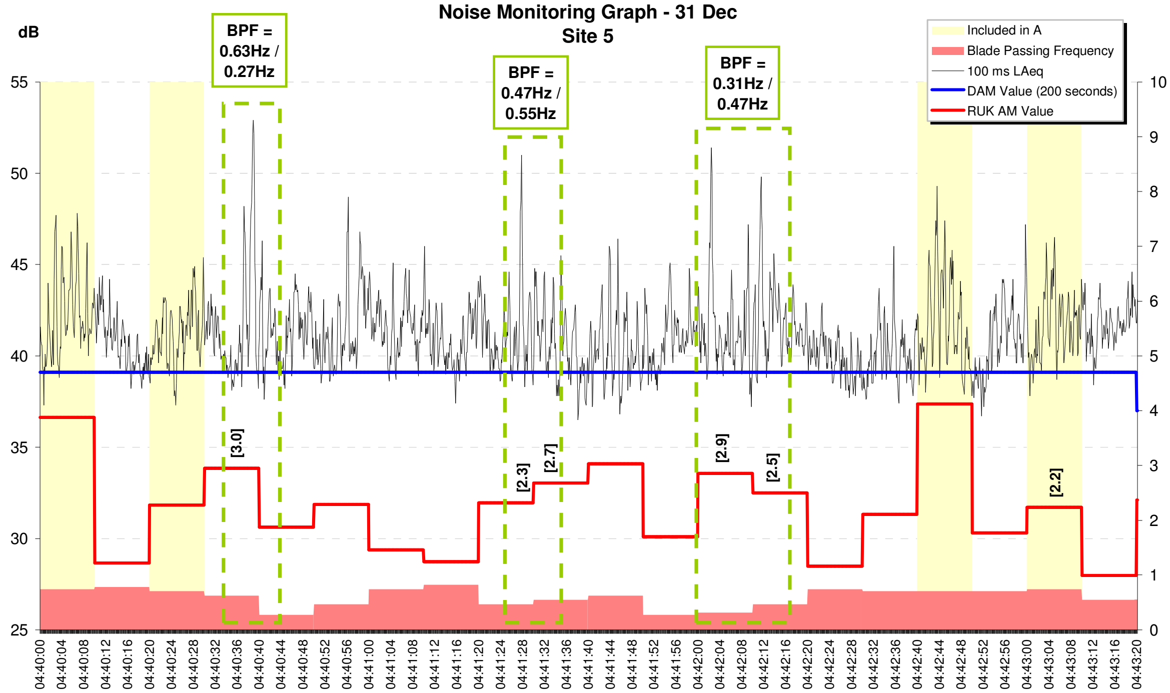

Figure 2: Cotton Farm - 31 Dec - 04:40 - example of inconsistent RUK blade pass frequencies.

The graph in Figure 3 compares the ReUK and D_{AM} methods where periods of sudden erratic loud AM occurs as illustrated by the dashed rectangular boxes. The periods highlighted in yellow are included by the ReUK procedure but the others are excluded. The exclusion of these high peaks arises whether a longer term or short term average BPF is used. The ReUK, RES, Den Brook and DAM methods for the 10 minute period from which figure 3 is taken are summarised in table 1 below.

Table 1: Summary of results from figure 3

Time	Description	Den Brook triggered? (approximate peak to trough value)	Renewable UK (RUK) AM value	RES Den Brook triggered?	Japanese DAM rating
0440	Wind farm noise dominant, windy but not much corrupting noise. AM more intermittent with sudden loud peaks. Some extraneous noise from local road traffic.	Yes. (≈5-15dB).	A = 2.9	Yes. Lots of periods >2.5 but also lots missed.	4.7 4.0 4.2

In summary the ReUK method considers the noise shown in figure 3 does not warrant a penalty. The RES method which is designed to automate the Den Brook control misses many events but hopefully would trigger further investigation. The D_{AM} method does indicate AM but does not relate its value to the erratic and highly intrusive variable noise that is experienced.

Figure 4 below shows a period where the RES method fails its objective. One difficulty with the procedure is whether to include harmonic sound energy of the BPF. This is discussed in relation to the graph below.

The period is approximately 2 minutes long. Plotted on the graph is the RES AM value calculated in accordance with the RES methodology and as plotted on the preceding graphs. This AM value is calculated only using the energy in the first peak of the modulation spectrum. Also plotted on the graph is the RES AM value if the energy at other dominant peaks, i.e. harmonics in the modulation spectrum, are included. The RES AM value calculated using just the first peak and the second peak (first harmonic) is also plotted on the graph. The red horizontal line gives the cut off value of 2.5. Labels have been provided above some of the 10s periods to indicate the typical peak to trough variation of the wind farm AM.

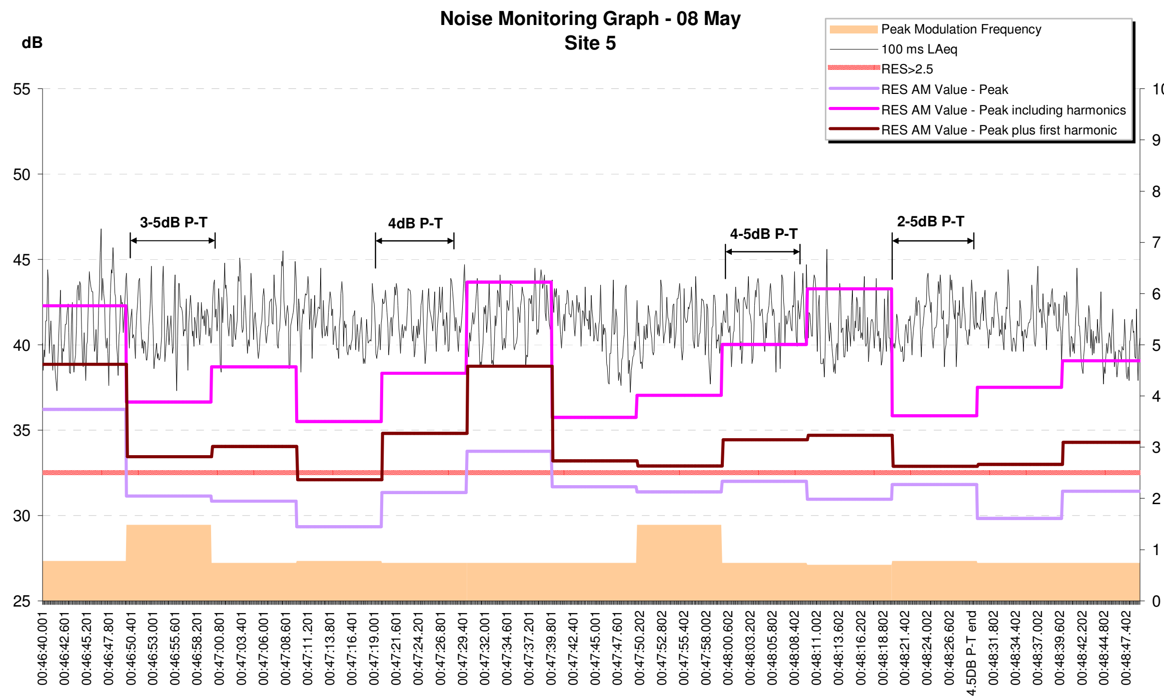

Figure 3: Cotton Farm - 8 May - 00:46 - differences in RES rating of AM values

Despite a fairly consistent modulating trace throughout the period only two 10s periods breach a RES AM value of 2.5, using the RES methodology with just the energy at the first peak of the modulation spectrum. Adding in energy from other harmonics to derive the AM value consistently increases the AM value above the value of 2.5. However, the value including all harmonics increases the difference between periods sometimes erratically and in some cases there is a large difference in AM value despite there being little difference in modulation depth.

5. Discussion

5.1 Discussion on the different test methods

There are many procedures in science where automated systems cannot yet replace human analysis. In the case of special characteristics the critical element is that any automated process does not exclude periods of noise impact that include special characteristics, otherwise their frequency, duration and degree of impact is understated. The MAS approach therefore has been to first filter data using human based observational techniques, then to use algorithmic procedures such as FFT to help refine the periods to focus upon, establish periods when the special characteristics occur, separate them according to the characteristic and then quantify the impact.

The traditional method and still the main method of assessment of compliance with noise level control in the vast majority of situations in the UK for more than 40 years has been to set a short period decibel limit (typically between 5 minutes to 1 hour) for a specified location using indices that can readily be determined. These include average equivalent level (LAeq) and is intended to reflect actual impact. Penalties for noise character are then sometimes applied but in the main would have been included to adjust the resulting limit before it was set.

In the event of an alleged breach the compliance assessor is then at liberty to use any scientific procedures at his / her disposal to determine the respective contributions to the sound environment and determine whether the particular site's emissions lead to exceedance of the immission level. Any assessment of compliance would need to take into account the uncertainty due to errors such as meter accuracy. Where exceedance is confirmed then it becomes necessary to determine whether the level, frequency of occurrence and duration of the breaches are *de-minimus* in which case it is not in fact a breach or whether in any event it is expedient and in the interests of the community to require compliance.

The main exception to this approach that has evolved, arises with the introduction of ETSU-R-97 in relation to wind farms and the use of 90th percentile values (LA90). Further discrepancy arises from a overly averaged process, LA90 values of wind turbine noise are averaged and compared to an average background noise environment. Compliance is increasingly becoming based on whether the average of the 90th percentile values exceeds a limit based on elevated thresholds when background levels are low. This exception was developed on the premise that wind turbine noise was effectively benign in character, being steady in nature and generally devoid of character when perceived at receptors, other than tonality.

It is a logical progression that the acceptance of the occurrence of special characteristics undermines the reliance on an approach based on elevated thresholds even when penalties are applied to reflect the inclusion of those characteristics. There is no evidence supporting acceptance of unpleasant sound content by communities at certain thresholds. Conversely the procedure identified in BS4142 and endorsed in the 2014 version, which rates the main characteristics of noise by applying a range of penalties and comparing the rated noise with the level of background noise, has merit. This principle of assessing noise in context is strongly supported by guidance from the WHO(8) and the British Standards.

It follows that any method that seeks to permit a level of noise disregarding its impact in context fails to protect. This argument is supported by the results of the data analysis of the ReUK procedure where a penalty is effectively deducted from the ETSU-R-97 noise limits. Independent analysis (See Figure 1) has shown the Cotton Farm Wind Farm was exceeding it limits at some locations but at times when the special characteristic excess amplitude modulation (EAM) occurred the 90th percentile turbine sound energy level was sufficiently below limits that the penalty did not result in a breach.

Correlation of community complaints and noise impact indicates that the main cause of complaints is this special characteristic, EAM, and that the application of a penalty does not result in its reduction in decibel level. Complaints also arise when the special characteristics occur at much lower decibel levels. The evidence clearly indicates that even if a penalty could be devised to reduce decibel levels at times when EAM occurs, the reductions considered would not change impact in any significant way until substantially lower levels were obtained.

Analysis of historical work indicates that a threshold of adverse impact may be about 26-28dB LAeq.[13] This most likely evolves from the level of masking noise present most of the time in soundscapes.

5.2 Determining limits of unacceptable AM.

Scientific discussion continues over what is an appropriate trigger point of unacceptability for AM in terms of modulation depth. Reliance only on modulation depth (MD) is considered a misleading approach to describing acceptability as a range of intrusive characteristics arise that do not necessarily relate to modulation depth or are not portrayed adequately by the “A” weighted values. A critical issue in relation to larger wind farms which does not appear to be given weight generally is that modulation depth is constrained, not so much by the background noise present but by the other wind farm noise content that is perceived more as a roar or continuous rumble.

The impact upon a receptor is a function of the imposition of special characteristics on top of the general turbine noise content whose contribution fluctuates much less. It is the combined impact and contrast of these two different characteristics which, when both are stopped, lead to a stark change in the soundscape. This is not depicted by change in modulation depth alone. Further, this is not depicted by artificially elevating the sound energy of the EAM as undertaken in laboratory research as it does not represent the contrasting noise content found in practice. This is illustrated in Figure 5 below which reflects a period when the turbines were stopped to measure the background noise. Impact relates also to frequency of occurrence, duration, times of impact and the consequences / effects of the intrusion.

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[13] Work of the Author in developing the Den Brook metric and condition in 2009 based on 4 wind farms and the studies into community response by Eja Pederson "Noise annoyance from wind turbines - a review" 2003

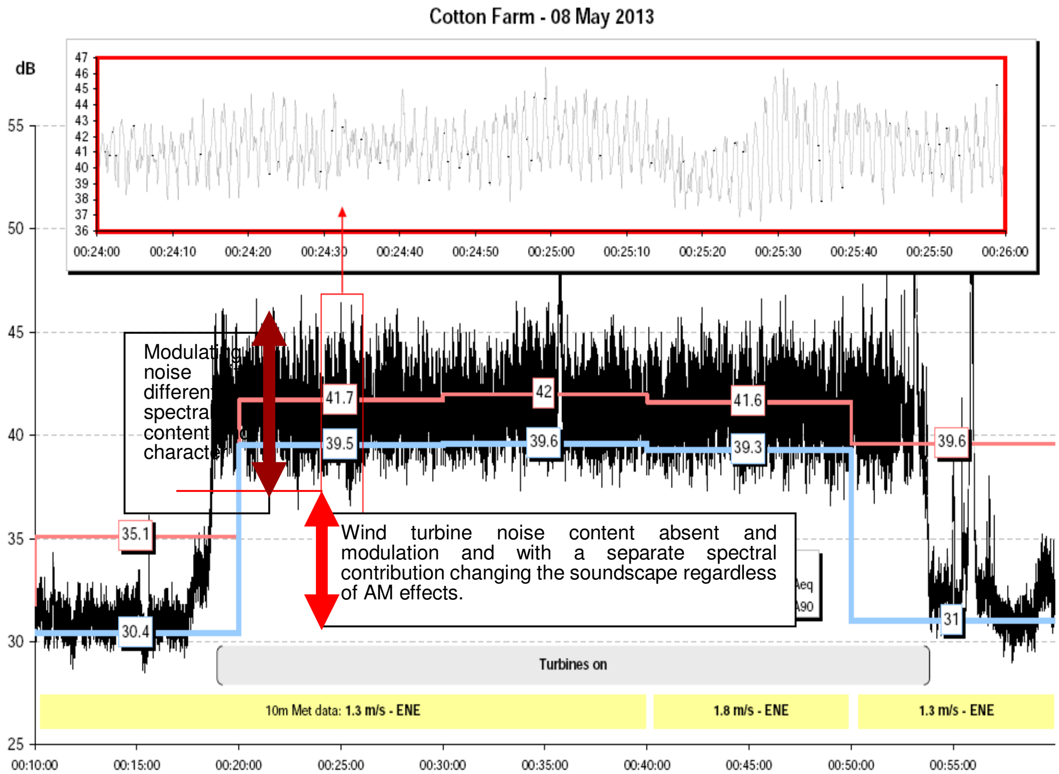

Figure 4: - Example 2 Cotton Farm 8th May 2013 – Switch on/off effect

5.3 Comparison with BS4142 (standard for industrial noise) using switch off test data

As discussed above BS4142 is used in the UK for other forms of industrial noise and has recently been updated to include a range of penalties to reflect the effect of noise character. This guidance considers noise impact on a context basis where limits reflect the extent of actual ambient masking noise in an environment.

Figure 6 below shows the change in level when switching on the turbine and allows a direct comparison between the relative methods for evaluating AM and this standard. The results of BS4142 assessment, both the new 2014 version and the 1997 version, are provided in table 2 below. Table 3 provides a summary of the AM methods (ReUK, RES, Den Brook, DAM) for the period shown in figure 6.

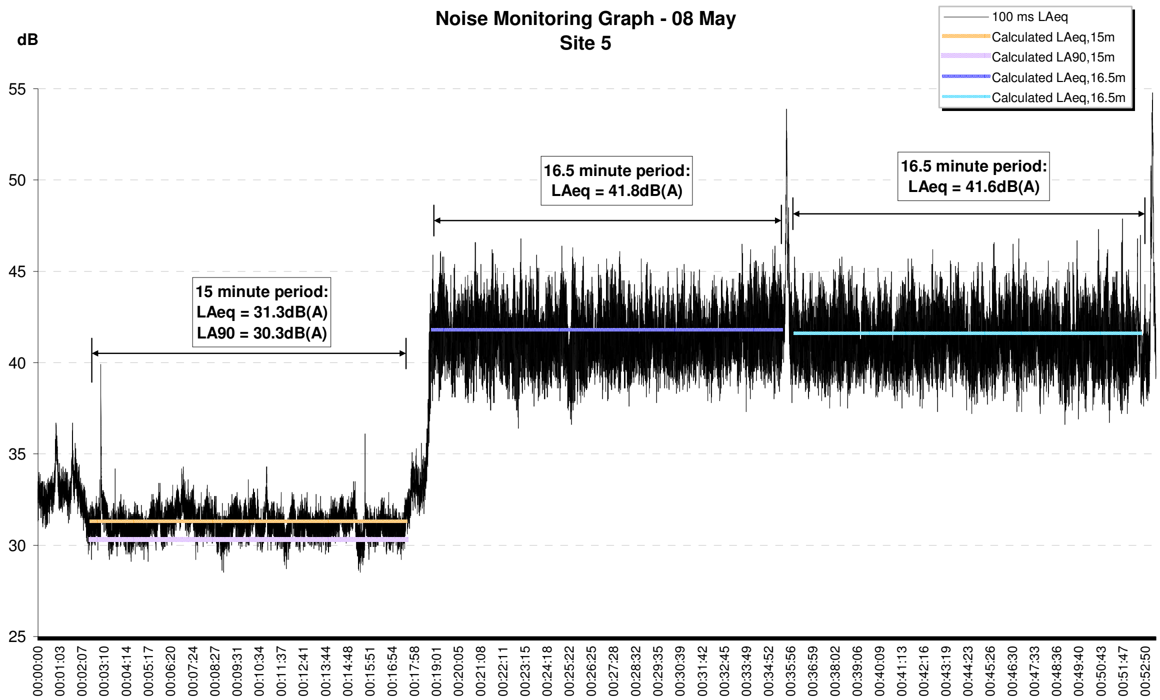

Figure 5: Cotton Farm - 8 May - 0000 - 0100 - BS4142 assessment

Table 2: BS4142 assessment - Cotton Farm - 8 May

	BS4142:1997	**BS4142:2014**
Measured background noise level	30.3dB LA90,5min	30.3dB LA90, 15min
Measured ambient noise level	41.7dB LAeq, 33min	41.7dB LAeq, 33min
Measured residual noise level	31.2dB LAeq, 5min 31.4dB LAeq, 5min (use 31.3dB LAeq, 5min)	31.3dB LAeq, 15min
Calculated turbine noise level (specific noise level)	41.3dB LAeq	41.3dB LAeq
Character penalty	+5dB for modulating character	Arguable +3-6dB for 'other sound character' and 'intermittency / readily distinctive'
Rated turbine noise level	46.3dB(A)	44.3 - 47.3dB(A)
Difference between rated turbine noise level and background noise level	+16dB	+14dB - 17dB

Table 3: Summary of AM assessment procedure results - Cotton Farm - 8 May

Time	Den Brook triggered? (approximate peak to trough value)	Renewable UK (RUK) AM value	RES Den Brook triggered?	Japanese DAM rating
0000	No. Less than 3dB MD	No. Nothing consistent with BPF. [A = 0.4]	No. All <2.5.	1.6 1.6 1.7
0010	Yes. (≈7dB) MD.	No. Not enough data points. [A = 2.3]	Yes. A few >2.5.	1.6 1.5 3.3
0020	Yes. (≈6-8dB) MD.	A = 4.1 [A = 4.1]	Yes. Lots of periods >2.5..	4.6 4.7 4.3
0030	Yes. (≈5-7dB) MD.	A = 3.8 [A = 3.8]	Yes. Lots of periods >2.5.	3.9 4.6 4.4
0040	Yes. (≈6-8dB) MD .	A = 3.8 [A = 3.8]	Yes. Lots of periods >2.5 but also lots missed.	4.5 4.4 4.6
0050	Yes. (≈5-9dB) MD.	A = 3.0 [A = 3.2]	Yes. Lots of periods >2.5 at start.	4.6 2.3 1.8

Note the LA90 value is below 40dB when the turbines are operating, demonstrating even a 3dB penalty could not address the noise impact or cause any change. As can be seen there is a huge mismatch where a level of +10dB is considered unacceptable impact when using BS4142 and with values up to 17dB derived following the procedure. The ReUK FFT method suggests the noise is acceptable and the D_{AM} method typically gives a value of 4-5. In this case the RES method, that is meant to reflect the Den Brook metric, does correctly trigger (identifies EAM).

Previously MAS have used a criterion of repetitive 3dBA modulation depth as an indicator of likely adverse impact, which is confirmed as clearly noticeable (1). The research shows the noise character becomes sensible at about 2dB modulation depth. In any event the soundscape is dominated by wind turbine noise when AM occurs including the more steady but spectrally different 'generic' immission and the AM.

The resulting noise is equivalent to an industrialised sound environment. This in turn suggests that an assessment methodology applied to the level of noise in context with the existing sound environment is required, especially whenever the sound contains special characteristics. This is consistent with the approach in BS4142 2014.

6. SUMMARY FINDINGS

6.1 What the new analysis of Cotton Farm WF data shows

The quickest and most effective means of analysing the special characteristic AM within WTN is firstly through manual assessor checks. This provides a quick method of excluding unusable data that is not subject to the flaws in automated algorithms.

Algorithms and procedures designed to automatically filter WTN datasets to exclude periods affected by extraneous noise but not exclude AM and based on FFT analysis of the BPF, have a high failure rate.

FFT procedures are yet to be shown to provide efficient algorithms for this type of highly variable sound energy and can miss periods of impact, be falsely triggered by extraneous noise or simply fail to reflect impact. The main procedure developed by ReUK was found to permit highly intrusive, erratic and unreasonable noise.

FFT derived procedures in a modified form to those currently presented by RES can be used as an extra evaluation tool to assist analysis of noise but only after initially filtering periods excessively corrupted by extraneous or absent AM.

FFT procedures are unhelpful when dealing with sound data containing erratically varying AM and erratically varying extraneous noise sources. There are also problems identifying AM where there are other character features such as tonality or lower frequency noise.

Impact from WTN containing special characteristics can best be assessed applying context procedures comparing against actual levels of background masking noise which are present during the periods of impact. This is best evaluated by comparing the periods before, during and after turbine switch off tests.

Application of special character penalties to threshold limits such as contained in ETSU-R-97 does not reflect impact and fails to reduce excess levels of adverse noise.

The revised standard BS4142 2014 has addressed concerns which led to its exclusion when ETSU-R-97 was written and now includes extended analysis of special characteristics in noise. This renders it suitable to WTN containing AM. Comparative tests show it is better suited at determining impact than ETSU-R-97 derived methods which are formulated on the absence of any significant character content.

Many commonly held views over frequency and duration of AM, when it occurs and how it should be rated, require revisiting. In particular the cumulative effect of AM and other characteristics of the wind turbine noise need to be considered and not just modulation depth.

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