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05 April 2024

Dear Ryan,

Re: BIOME RENEWABLES – FEATHEREDGE® TECHNOLOGY

We have been reviewing the FeatherEdge® serration technology developed by Biome Renewables with great interest. The present letter sets out our analysis of the acoustic performance of this blade addition which demonstrates potential substantial noise reductions, above and beyond the current state of the art technology. This could have transformative consequences for the wind industry via the reduced noise impact of wind energy projects on neighbouring populations, in turn leading to increased flexibility in design and the potential for maximising energy generating capacity. I will first summarise our experience in the field and set out our analysis of initial results based on the details of this new technology which you provided.

Our profile

Hoare Lea's acoustic group is one of the UK's largest and longest established acoustic consultancies. Our wind farm experience stretches back to 1990. Hoare Lea (HL) assists in planning issues relating to noise from proposed wind farms as well as in the continued development of quiet wind turbine designs and in the measurement and reduction of noise from built wind farms.

The group's wind farm experience now extends to over 250 wind farms both within the UK, Ireland and abroad, acting as independent noise consultants for wind turbine manufacturers, wind farm developers, local authorities, and private individuals alike. Hoare Lea's work on wind farms includes a wide range of projects, at all scales across the UK and Ireland, both pre- and post-construction. This notably includes Whitelee Wind farm and its extensions, now the UK's largest onshore wind farm with 215 turbines. ScottishPower Renewables (part of the Iberdrola Group) recognised this by naming Hoare Lea as a leading Corporate Social Responsibility contractor in their 2017 supplier awards.

Two of Hoare Lea's team were members of UK Noise Working Group whose remit was to agree the procedures used in the UK for assessing the environmental impact of wind turbine noise. I am also part of a working group of the UK Institute of Acoustics which sets out good practice in the field. Hoare Lea also managed a large research project commissioned in 2011 by Renewable UK to improve the understanding of amplitude modulation noise from wind turbines and therefore has industry-leading experience of this complex subject. We have also undertaken and published research on the topic of noise propagation where we have extensive knowledge. HL engineers have provided expert witness evidence at more than 30 wind UK farm planning appeals or hearings, as well as some high-profile court cases.

Noise and power

The influence of different noise assessments on the viability, risk and generating capacity of wind farm developments is frequently underestimated. Through experience, we know that seemingly small changes to environmental noise limits or assessment methodologies can translate to substantial lost renewable energy generation and development opportunities. Where noise is a constraint due to proximity to noise-sensitive locations, even a difference of 2 or 3 dB, which would just be perceptible, could translate into a 40% reduction or enhancement of the energy generating potential of a scheme. This is because increased separation distance is often the main mitigation measure available and, where development area is limited, this will translate into a reduced project scale. As the uptake of wind energy across the UK and worldwide grows, controlling cumulative noise impacts is becoming increasingly important and can in some cases translate into even more significant noise constraints.

The advent of variable speed, pitch-regulated wind turbine technology has led to an efficient design in terms of noise emissions from modern turbines, leading to low noise emissions at low wind speeds and then increasing to a noise emission peak at or close to the turbine rated power, with noise emissions then either staying constant or decreasing at the highest wind speeds. Noise emissions are now dominated by the trailing edge[1] of the turbine blade.

The next technological step was the creation of Serrated Trailing Edge (STE) technology, typically providing an extra 2 dB(A) reduction at source at no energy cost, and these are now available as standard on most commercial turbine models. This noise reduction has compensated for the potential increases in noise which may have been the consequence of the increasing size of modern turbines with rotor diameter in excess of 100 m. Our previous understanding was that STE blades represented the state-of-the art, and that further reduction could only be obtained in practice through the use of noise-reduced operational modes, which slow the turbine rotation and therefore reduce energy generation.

FeatherEdge technology

Based on the above summary, we were very interested in the potential for the FeatherEdge technology to provide reductions beyond those of a standard STE-equipped blade. We understand that this blade addition was designed to provide further reduction in trailing edge noise through targeted cancellation of the noise generation mechanism on the blade trailing edge.

Biome Renewables provided to Hoare Lea extracts from a test document provided by Deutsche WindGuard. The supplied document reports a comparative *in-situ* test on an operational 3 MW capacity turbine. Test measurements were undertaken in accordance with the IEC 61400-11 (ed. 3) standard, which is the applicable methodology for testing noise emissions from wind turbines. The comparative test measurements were between the same turbine with the standard STE provided by the turbine manufacturer and then with the blades equipped instead with FeatherEdge. The data provided was the relative difference in the noise emission (at source) spectrum[2] level between STE and FeatherEdge. This showed that:

- At a medium/moderate wind speed[3], where turbines would normally reach their maximum noise emission level:
    - the relative reduction of FeatherEdge at source on the overall, A-weighted[4] levels was around **3.4 dB(A).**
    - In addition, the effect of FeatherEdge was to provide a frequency shift, with an increase of noise at higher frequencies (2 kHz and above) but with a stronger decrease of lower frequencies below 1 kHz.
    - In particular, an apparent reduction of **between 6 and 8 dB for key frequencies of 200 to 800 Hz** was observed, which is very large and unprecedented in our experience.
- At lower wind speeds[5], where turbine noise emissions tend to be lower:
    - The effect on overall levels at source was reduced (less than 1 dB(A)).
    - However, **a shift towards high frequencies** and a reduction at lower frequencies, although less pronounced, was still clearly apparent, with **reductions below 200 Hz circa 4 to 6 dB.**

[1] The thin end of the blade which does not face into the direction of the rotation of the blade.

[2] A description of the amplitude of a sound as a function of frequency or "pitch".

[3] Hub height wind speeds around 10 m/s corresponding to a "standardised" wind speed of 7 m/s (at a notional height of 10 m in accordance with the conventions of the IEC 61400-11 standard.

[4] A-weighting is a filter that represents the frequency response of the human ear when assessing the likely effects of noise, providing a single-number representation of a sound spectrum.

[5] 6 to 8 m/s at hub height or 4 to 6 m/s standardised 10 m height wind speeds.

The effect of noise propagation

This shift in frequency is particularly relevant given the effects of noise propagation. Whilst the sound emission test under IEC 61400-11 is undertaken in relative proximity to the turbine (one tip height away, typically 100-150 m from the turbine tower), noise-sensitive receptors are located further away (typically 500 to 2000 m or more depending on the circumstances). Over this distance, the effect of air absorption in particular means that high frequency sounds above 2 kHz dissipate strongly whereas lower frequency sounds attenuate less. This means that the effect of the FeatherEdge frequency shift will be much larger in practice than suggested by the sound emission testing once the frequency dependent attenuating effect of atmospheric propagation over larger distances is accounted for.

Figure illustrating the factors considered in the study of atmospheric propagation

To evaluate this, we modelled the potential effect of the reduction based on the data provided by applying it to the emission spectrum of a modern turbine (rotor diameter >100m, power generation around 3 MW), comparing the standard model with STE and with the potential reduction offered by FeatherEdge. Different turbine layout configurations were modelled using the ISO 9613-2 standard, recognised as a practical engineering method which is effective at modelling sound propagation over typical distances. The results indicated that:

- At medium/moderate wind speeds:
  - The sound level reduction (relative to a standard STE) improved from 3 dB(A) to **5 to 6 dB(A) at distances of 500m and above**, which represents a large and clearly noticeable noise reduction.
  - Depending on the turbine layout configuration and location, this level of noise reduction would mean equivalent levels would be obtained with a separation distance from turbine to receiver reduced by **400 to 800 m**. This is comparable to the typical minimum separation distances between turbines of >100m rotor diameter (to minimise wake effects). This could therefore allow, subject to other constraints and design considerations, a substantial increase in generation capacity, potentially allowing for example an extra row of turbines in a wind farm.
  - To obtain a similar level of noise reduction with noise-optimised operational modes would be possible but with estimated peak power generation losses of **more than 50 %**.
- At lower wind speeds:
  - The effective sound level reduction relative to a standard STE was also improved, with a **1 to 2 dB(A) at distances of 500m and above**.
  - This would still be equivalent to a reduced separation distance from turbine to receiver of **150 to 350 m**.
  - Noise-reduced operational modes with similar noise reduction could be associated with power losses of the order of **2 to 5%**.

Comments and Next Steps

Based on the observations from Deutsche WindGuard that the introduction of FeatherEdge did not have an effect on the power generation of the turbine tested, the above initial results, if confirmed, would equate to an unprecedented level of noise reduction relative at no cost to the generated power. This technology could therefore represent a potential "game-changer" in turbine operational noise control of aerodynamically generated noise.

In the UK, the installed onshore wind capacity recently reached 15 GW[6]. The possibility of retro-fitting this technology to existing windfarms which are constrained in their operation due to noise could therefore be potentially be very large. This is in addition to the potential for newly designed and developed sites.

We would welcome further confirmed data showing tested results over the whole wind speed range using the FeatherEdge technology, with a range of modern wind turbine models. This would enable us to recommend this technology to provide additional effective noise mitigation where required and design future noise-optimised wind farms. If our initial conclusions based on our analysis to date continue to hold, it is our view FeatherEdge technology could be significant enabler in the current climate emergency through their ability to maximise energy generation from wind energy developments through the greater control of noise impacts on noise sensitive receptors and could become the standard STE technology in time.

Yours sincerely,

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Ref: LET-Biome-MC-20240405-FeatherEdge initial evaluation-2.docx

[6] https://www.renewableuk.com/news/666925/UK-reaches-major-new-clean-energy-milestone-15-gigawatts-of-onshore-wind-.htm