Assessment of wind turbine noise and residual noise in immission areas around wind power plants

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ABSTRACT
In wind turbine noise problem, not only the noise level caused by wind turbines, but also the noise emergence, the increase of the noise level caused by wind turbines over the residual noise (background noise without any specific noises) is important. To investigate this matter, the noise levels around 17 wind farms across Japan under operating and ceasing conditions were measured. In addition, residual noises in four kinds of regions (rural, coastal, urban residential, and industrial districts) were measured. As a result, the actual condition of the noise emergency caused by wind turbines and the difference of residual noise between daytime and nighttime have been known for respective types of districts. For the assessment of the noise levels under both conditions with/without wind turbine noise should be evaluated in terms of equivalent level ($L_{Aeq}$). When measuring $L_{Aeq}$, however, it is necessary to strictly eliminate extraneous noises such as pass-by noise of road vehicles, fly-over noise of aircrafts and creatures’ sounds. This procedure is very troublesome and therefore we examined the method estimating $L_{Aeq}$ statistically from the 90 percentile sound level ($L_{A90}$) which is very robust against transient extraneous noise.

Keywords: Wind turbine noise, Residual noise

1. INTRODUCTION

Wind power generation plants are generally constructed in quiet rural districts. In these environments, there are various transient background noises (BGNs) such as automobile noise, aircraft noise and the sounds of various creatures, but very quiet condition with only residual noise (noise floor) without such specific background noises last for a long time, especially during nighttime. Therefore, the noise emergence, the increase of environmental noise by wind turbine noise (WTN) should be considered in WTN problem.

When measuring WTN and residual noise, they are apt to be seriously disturbed by the transient background noises. In this paper, therefore, the method for eliminating the effects of background noises in the measurements of WTN and residual noise are discussed. The results of the measurement of residual noise conducted in four kinds of districts in Japan with different local characteristics are also introduced.

2. NOISE EMERGENCE BY WIND TURBINE NOISE

WTN should be assessed in terms of equivalent continuous A-weighted sound pressure level, $L_{Aeq}$, in common with other environmental noises. However, WTN in immission areas is relatively low and it is apt to be influenced by the background noises [1]. Figure 1 shows an example of A-weighted sound pressure level (A-weighted SPL) with Fast time-weighting measured at a point 1.2 km apart from a wind turbine (2.4 MW), in which a pass-by noise of a road vehicle was included. In this case,
the value of $L_{Aeq}$ increased by 3 dB when the background noise was included. When assessing the WTN, therefore, such background noises have to be carefully excluded. This processing (BGN exclusion processing) is very troublesome and time-consuming.

In the nationwide field measurements of WTN conducted in Japan in 2010-2012 [2], the data for the environmental noise measured when the wind turbines were in operation and when they stopped have been obtained for 84 measurement points around 17 wind farms across Japan. The results are shown in Figures 2 and 3, in which Figure 2 is for $L_{Aeq}$ during nighttime when the wind turbines were in operation ($L_{Aeq,WTN,n}$) and Figure 3 is for $L_{Aeq}$ during nighttime without WTN (residual noise : $L_{Aeq,rec,n}$). When obtaining these sound level data, the effect of background noises was carefully eliminated through level recordings and hearing check for the recorded sounds. In the result shown in Figure 2, a tendency was seen that $L_{Aeq,WTN,n}$ decreased with increasing the distance from the nearest wind turbine. On the other hand, in Figure 3, the level of the residual noise ($L_{Aeq,rec,n}$) much depended on the measurement sites, distributed from about 20 dB to 40 dB.

From these data, the noise emergence was calculated as the level difference between $L_{Aeq,WTN,n}$ and $L_{Aeq,rec,n}$ as shown in Figure 4. In this result, it can be seen that the noise emergence was larger as the measurement point was nearer to the wind turbine and as the residual noise level was lower. The noise emergence ranged about from 5 dB to 20 dB within the distance of 500 m from the nearest wind turbine and it was less than 10 dB beyond that distance. When assessing the effect of WTN, not only the noise level when the wind turbines are in operation but also the residual noise level which indicate the “quietness” of the district should be taken into account.

![Figure 1 – An example of A-weighted SPL of WTN including background noise. (horizontal distance: 1.2 km, wind turbine: 2.4 MW)](image-url)
Figure 2 – WTNs in the residential areas around wind farms at nighttime.

Figure 3 – Residual noises in the residential areas around wind farms at nighttime.

Figure 4 – Noise emergence as a function of distance.
3. ASSESSMENT OF WIND TURBINE NOISE

3.1 Effect of background noise on wind turbine noise measurement

The noise level of WTN in immission areas is generally low and hence apt to be influenced by the background noise as shown in Figure 1, and when obtaining $L_{Aeq}$ of WTN by the normal time-integration, the BGN exclusion processing is essential.

As an alternative method to assess the WTN, 90 percentile sound level, $L_{A90}$, is used in some countries such as the UK, New Zealand and South Australia [3,4,5]. To examine the applicability of such statistical indicators, the data of WTN recorded for 3 min at 81 points around 18 wind farms in Japan were analyzed in terms of $L_{Aeq}$, $L_{A90}$ and $L_{A95}$ with and without BGN exclusion processing. Each of the correspondence between the level with BGN exclusion processing and that without the processing for the three indicators is shown in Figures 5 (a), (b), and (c), respectively. Here, the three levels obtained with BGN exclusion processing are expressed as $L_{Aeq,WTN}$, $L_{A90,WTN}$, $L_{A95,WTN}$, respectively, and those obtained without the processing are expressed as $L_{Aeq,tot}$, $L_{A90,tot}$, $L_{A95,tot}$, respectively. In the result for $L_{Aeq}$, some serious differences are seen by the effect of the background noise up to 27 dB. On the other hand in the results for $L_{A90}$ and $L_{A95}$, the difference between with and without BGN exclusion processing is hardly seen, which means $L_{A90}$ and $L_{A95}$ are very robust against the effect of transient background noises.

![Figure 5](image-url)

(a). $L_{Aeq,tot}$ vs. $L_{Aeq,WTN}$

(b). $L_{A90,tot}$ vs. $L_{A90,WTN}$

(c). $L_{A95,tot}$ vs. $L_{A95,WTN}$

Figure 5 – Effect of eliminating background noise for $L_{Aeq}$, $L_{A90}$ and $L_{A95}$
3.2 Correlation between $L_{A_{eq}}$ and $L_{AN}$ of wind turbine noise

Next, the correlation between $L_{A_{eq},WTN}$ and $L_{A_{90},tot}$, and that between $L_{A_{eq},WTN}$ and $L_{A_{95},tot}$ were investigated. As shown in Figures 6 (a) and 6 (b), a very high correlation with correlation coefficient larger than 0.99 is seen in both cases. The mean of the difference between $L_{A_{eq},WTN}$ and $L_{A_{90},tot}$ was 2.1 dB (standard deviation: 0.73) and that between $L_{A_{eq},WTN}$ and $L_{A_{95},tot}$ was 2.5 dB (standard deviation: 0.91) as shown in Table 1. From these results, it has been found that $L_{A_{eq}}$ of WTN can be statistically estimated from $L_{A_{90}}$ or $L_{A_{95}}$ without making troublesome and time-consuming BGN exclusion processing.

![Graphs showing correlation between $L_{A_{eq},WTN}$ and $L_{A_{90},tot}$ and $L_{A_{95},tot}$](image)

(a). $L_{A_{eq},WTN}$ vs. $L_{A_{90},tot}$

(b). $L_{A_{eq},WTN}$ vs. $L_{A_{95},tot}$

Figure 6 – Correlation between $L_{A_{eq},WTN}$ and $L_{AN,tot}$

<table>
<thead>
<tr>
<th>SPL index</th>
<th>Average</th>
<th>Standard deviation</th>
<th>Maximum value</th>
<th>Minimum value</th>
</tr>
</thead>
<tbody>
<tr>
<td>$L_{A_{eq},WTN} - L_{A_{90},tot}$</td>
<td>2.1</td>
<td>0.73</td>
<td>5.0</td>
<td>0.8</td>
</tr>
<tr>
<td>$L_{A_{eq},WTN} - L_{A_{95},tot}$</td>
<td>2.5</td>
<td>0.91</td>
<td>5.9</td>
<td>1.1</td>
</tr>
</tbody>
</table>

4. ASSESSMENT OF RESIDUAL NOISE

As mentioned earlier, the noise emergence by the operation of wind turbines should be seriously considered in WTN problem. Therefore, the residual noise (environmental noise without WTN and other specific background noises) should be observed in terms of $L_{A_{eq}}$ as the initial condition.

4.1 Field measurements of residual noise in four kinds of areas

To investigate the actual state of the residual noise not only in quiet rural districts but also including other areas with various local characteristics, field measurements were conducted in four kinds of areas: (1) rural, (2) coastal, (3) urban residential, and (4) industrial districts. For each district, three measurement sites were chosen across Japan. In the measurement of residual noise, the effect of transient background noises is very serious and therefore the BGN exclusion processing through level recordings and hearing check for the recorded sounds were carefully conducted for all the data.

The measurement results of residual noise in terms of $L_{A_{eq}}$ ($L_{A_{eq,res}}$) for the four kinds of districts are shown in Figure 7 in the form of histogram and Table 2. The energy-mean values of $L_{A_{eq,res}}$ for the respective districts were 35 dB (rural), 40 dB (coastal), 41 dB (urban residential), and 48 dB (industrial) for daytime and 29 dB (rural), 35 dB (coastal), 37 dB (urban residential), and 45 dB (industrial) for nighttime and the order of the residual noise level was rural < coastal ≤ urban residential < industrial. The level difference between during daytime and nighttime was 6 dB (rural),
5 dB (coastal), 4 dB (urban residential), and 3 dB (industrial); 5 dB on average.

Figure 7 – Histogram of $L_{Aeq,res}$ of residual noises in four kinds of districts
### Table 2 – Statistical values of \( L_{\text{Aeq, res}} \) in four kinds of districts [dB]

<table>
<thead>
<tr>
<th>Reference time interval</th>
<th>Districts</th>
<th>( L_{\text{Aeq, res}} ) [dB]</th>
<th>Average</th>
<th>Standard deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Daytime (06-22)</td>
<td>Rural</td>
<td>35</td>
<td></td>
<td>4.0</td>
</tr>
<tr>
<td></td>
<td>Coastal</td>
<td>40</td>
<td></td>
<td>5.2</td>
</tr>
<tr>
<td></td>
<td>Urban residential</td>
<td>41</td>
<td></td>
<td>4.8</td>
</tr>
<tr>
<td></td>
<td>Industrial</td>
<td>48</td>
<td></td>
<td>5.8</td>
</tr>
<tr>
<td>Nighttime (22-06)</td>
<td>Rural</td>
<td>29</td>
<td></td>
<td>4.5</td>
</tr>
<tr>
<td></td>
<td>Coastal</td>
<td>35</td>
<td></td>
<td>5.3</td>
</tr>
<tr>
<td></td>
<td>Urban residential</td>
<td>37</td>
<td></td>
<td>5.1</td>
</tr>
<tr>
<td></td>
<td>Industrial</td>
<td>45</td>
<td></td>
<td>3.8</td>
</tr>
</tbody>
</table>

### 4.2 Correlation between \( L_{\text{Aeq}} \) of residual noise and \( L_{\text{AN}} \) of total noise

When obtaining the level of residual noise in terms of \( L_{\text{Aeq}} \) mentioned in 4.1, the BGN exclusion processing was performed thoroughly. But it was very troublesome and so the way of estimating \( L_{\text{Aeq}} \) from \( L_{\text{AN}} \) was investigated as follows.

The correspondences between \( L_{\text{Aeq, res}} \) (\( L_{\text{Aeq}} \) of residual noise obtained with BGN exclusion processing) and \( L_{\text{AN, tot}} \) (\( L_{\text{AN}} \) of the total noise) for daytime and nighttime are shown in Figure 8 (a) and 8 (b), respectively, in which it has been found that the two indicators are highly correlated with a correlation coefficient larger than 0.99. The mean of the difference between \( L_{\text{Aeq, WTN}} \) and \( L_{\text{AN, tot}} \) was 1.5 dB (standard deviation: 0.61) for daytime and 1.4 dB (standard deviation: 0.67) for nighttime as shown in Table 3. This fact indicates that \( L_{\text{Aeq, res}} \) can be statistically estimated from \( L_{\text{AN, tot}} \) which can be easily obtained without the BGN exclusion processing.

Figure 8 – Correlation between \( L_{\text{Aeq, res}} \) of residual noises and \( L_{\text{AN, tot}} \) of total noises

### Table 3 – Statistical values of SPL differences between \( L_{\text{Aeq, res}} \) and \( L_{\text{AN, tot}} \) [dB]

<table>
<thead>
<tr>
<th>Reference time interval</th>
<th>Average</th>
<th>Standard deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Daytime (06-22)</td>
<td>1.5</td>
<td>0.61</td>
</tr>
<tr>
<td>Nighttime (22-06)</td>
<td>1.4</td>
<td>0.67</td>
</tr>
</tbody>
</table>
5. CONCLUSIONS

The methods for the measurement and assessment of WTN have been discussed in this paper. Its conclusions are as follows.

1) In the WTN problem, not only the sound level of WTN but also the noise emergence, the increase of environmental noise caused by the operation of wind turbines, should be considered. In this study, the noise emergence was examined for the measurement results for 84 measurement points at 17 wind farm sites across Japan. As a result, it was found that the noise emergence was larger as the measurement point was nearer to the wind turbine and as the residual noise level was lower. The noise emergence ranged about from 5 dB to 20 dB within the distance of 500 m from the nearest wind turbine and it was less than 10 dB beyond that distance.

2) Regarding the measurement of WTN, $L_{Aeq}$ obtained with careful BGN exclusion processing and $L_{A90}$ or $L_{A95}$ without the processing were highly correlated and it can be concluded that $L_{Aeq}$ of WTN can be statistically estimated from $L_{A90}$ or $L_{A95}$ with a fairly high accuracy.

3) The actual state of the residual noise was investigated by performing the field measurements in four kinds of districts with different local characteristics in Japan. The energy-mean values of $L_{Aeq,\text{res}}$ for the respective districts were 35 dB (rural), 40 dB (coastal), 41 dB (urban residential), and 48 dB (industrial) for daytime and 29 dB (rural), 35 dB (coastal), 37 dB (urban residential), and 45 dB (industrial) for nighttime. The level difference between during daytime and nighttime was 5 dB on average.

4) The noise level of the residual noise in the environment should be assessed in terms of $L_{Aeq}$ in principle, but it needs troublesome BGN exclusion processing. As an alternative method, $L_{Aeq}$ can be statistically estimated from $L_{A90}$ for the total noise without the BGN exclusion processing.

6. ACKNOWLEDGEMENT

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