Design and application of sound barrier for substation noise control

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Abstract. After measuring the noise of transformers, substation boundary and noise-sensitive area of a 110 kV substation, it’s known that the noise at substation boundary contains transformer noise component via analyzing the 1/3-octave band spectrums. The octave band sound pressure level on the roof of the east residential building derived from the transformer is obtained by sound field prediction of SoundPLAN. Moreover, the NR-40 curve is used to evaluate the octave band sound pressure level to calculate the theoretical noise reduction of the east residential building. Considering the direct propagation and another propagation path undergoing reflection, a sound barrier that composed of sound insulation board with a significant sound insulation effect is designed for the frequency band below 1000 Hz. After completely installing the sound barrier, the noise level at measuring point 16 at night is reduced from 55.9 dB(A) to 46.7 dB(A), with noise reduction of 9.2 dB(A); while it is reduced from 56.3 dB(A) to 44.5 dB(A) at measuring point 21, with noise reduction of 11.8 dB(A).

1. Introduction

With the increasing of residential power consumption, more substations are built in densely populated areas. The corresponding environmental pollution problems are aggravated, among which the most prominent one is noise pollution. In China, the AC frequency is 50 Hz, leading the noise emitted by the transformer is at the first 20 harmonic frequencies of 50 Hz, which contains low-frequency components. Studies have shown that low-frequency noise not only adversely affects physical health, but also interferes with behavior and cognition [1-4]. Due to the long-term and stable noise emission from transformers, the impact on residents is particularly serious. Therefore, solving the problem of transformer noise pollution has been an important issue.

Some progress has been made in the research of active noise control of substations, but the noise reduction effect of this method is difficult to fully cover in space, and it has poor effect in the noise-sensitive area. It is still difficult to solve the problem of disturbing residents [5-7]. Di successfully reduces the subjective annoyance caused by transformer noise by adding narrow-band pink noise with the frequency range of 200-770Hz via the method of sound adjustment and control (SAC) [8]. Though this method is applicable to the scene where the substation noise level is lower than the standard limit but still disturbs the surrounding residents, it is not applicable to the substation that needs to solve the
problem that the noise exceeds the standard limit. In addition to active control, a method of suppressing noise propagation can also be used by using sound-absorbing and insulating materials. Zhang studied the sound absorption performance of a series of materials at different frequencies based on the noise characteristics of the transformer [9]. Liu have made research on noise control of substation, which noise control program is installing an overall BOX-IN structure [10]. This paper proposes a method using sound barrier for transformer noise control, including the calculation of noise reduction of noise-sensitive area and the height of sound barrier.

2. Problem description
A 110 kV semi-indoor substation was built in 2005 with three transformers and a building with a height of 17.2 m. According to on-site investigation, there are residential buildings on the east, south and northeast of the substation. Residents in the east and northeast complained that the substation noise interfered with work and life.

3. On-site measurement before noise control

3.1. Standard limits
According to the Chinese standard of GB 12348-2008, the emission limits at the substation boundary in the daytime(06:00-22:00) and night-time(22:00-06:00) are 60 dB(A) and 50 dB(A), respectively; according to the Chinese standard of GB 3096-2008, the noise limits of the noise-sensitive area in the daytime and night-time are 60 dB(A) and 50 dB(A).

3.2. Measurement method
Transformer noise is measured on the prescribed contour, which is 0.3 m away from the principal radiating surface. The principal radiating surface is a chord contour line around the transformer, formed by moving vertically from the top of the cover to the bottom. The transformer noise is measured at the height of 1/3 of the oil tank, and the measuring points (1 to 12) are shown in Figure 1.

Figure 1. Location map of noise measurement points.
3.3. Measurement results
Transformer noise measurement results are shown in Table 1. The noise level of transformer #1 is between 66.8 ~ 71.8 dB(A), transformer #2 is between 63.5 ~ 71.3 dB(A), transformer #3 is between 69.9 ~ 71.2 dB(A). Figure 2 shows the 1/3-octave band spectrums of the three transformers, illustrating that sound pressure level is prominent at 100 Hz, 200 Hz, 315 Hz, 500 Hz and 630 Hz.

| Transformer | Measuring points | $L_{Aeq}$ / dB(A) |
|-------------|------------------|------------------|
| #1          | 1                | 66.8             |
|             | 2                | 71.8             |
|             | 3                | 70.9             |
|             | 4                | 70.6             |
| #2          | 5                | 66.4             |
|             | 6                | 68.6             |
|             | 7                | 63.5             |
|             | 8                | 71.3             |
| #3          | 9                | 69.9             |
|             | 10               | 70.7             |
|             | 11               | 70.6             |
|             | 12               | 71.2             |

As shown in Table 2, the A-weighted sound pressure level of measuring points 13~20 at substation boundary in the daytime is lower than the limit of GB 12348-2008, while the A-weighted sound pressure level of measuring points 14~17 in the night-time exceeds the limit of GB 12348-2008. The maximum
noise level in the night-time is 55.9 dB(A) at the measuring point 16, which is 5.9 dB(A) higher than the limit.

Table 2. Noise level at substation boundary before noise control.

| Measuring points | $L_{Aeq}$ / dB(A) | Evaluations | $L_{Aeq}$ / dB(A) | Evaluations |
|------------------|-------------------|-------------|-------------------|-------------|
|                  | Daytime [a] Limit [b] |            | Night-time [a] Limit [b] |            |
| 13               | 57.5 60            | Qualified   | 47.6 50           | Qualified   |
| 14               | 58.5 60            | Qualified   | 51.5 50           | Not-qualified |
| 15               | 59.7 60            | Qualified   | 53.3 50           | Not-qualified |
| 16               | 58.6 60            | Qualified   | 55.9 50           | Not-qualified |
| 17               | 56.5 60            | Qualified   | 52.9 50           | Not-qualified |
| 18               | 59.7 60            | Qualified   | 48.8 50           | Qualified   |
| 19               | 60.0 60            | Qualified   | 48.5 50           | Qualified   |
| 20               | 58.9 60            | Qualified   | 48.2 50           | Qualified   |

[a] According to Chinese standard of GB 12348-2008. [b] Measurement result has been corrected using background noise level based on standard of GB 12348-2008.

Table 3. Noise level in the noise-sensitive area before noise control.

| Measuring points | $L_{Aeq}$ / dB(A) | Evaluations | $L_{Aeq}$ / dB(A) | Evaluations |
|------------------|-------------------|-------------|-------------------|-------------|
|                  | Daytime Limit [a] |            | Night-time Limit [a] |            |
| 21               | 56.2 60           | Qualified   | 56.3 50           | Not-qualified |
| 22               | 57.2 60           | Qualified   | 49.5 50           | Qualified   |

[a] According to standard of GB 3096-2008.

4. Noise control method

4.1. Calculation of noise reduction of noise-sensitive building

Table 4. Theoretical noise reduction.

| Frequency / Hz | Simulation result / dB | $NR-40$ / dB | Theoretical noise reduction |
|----------------|------------------------|--------------|----------------------------|
| 31.5           | 7.7                    | 82.6         | 0                          |
| 63             | 27.2                   | 67.1         | 0                          |
| 125            | 47.7                   | 56.8         | 0                          |
| 250            | 50.8                   | 49.2         | 1.6                        |
| 500            | 54.2                   | 43.8         | 10.4                       |
| 1000           | 40.8                   | 40.0         | 0.8                        |
| 2000           | 31.6                   | 37.1         | 0                          |
| 4000           | 25.3                   | 34.9         | 0                          |
| 8000           | 19.5                   | 33.1         | 0                          |

The octave band sound pressure level on the roof of the residential building on the east of substation is simulated with SoundPLAN. The $NR-40$ curve is used to evaluate the octave band sound pressure level obtained by simulation to determine the theoretical noise reduction of the noise-sensitive building, thereby facilitating the design of the sound barrier. The theoretical noise reduction at 250 Hz, 500 Hz and 1000 Hz of the sensitive points of residents must be greater than 1.6 dB, 10.4 dB and 0.8 dB respectively, as shown in Table 4 and Figure 3.
4.2. Design of sound barrier

The noise of the substation boundary and noise-sensitive buildings should be lower than the limit in the
daytime and night-time respectively after noise control. Therefore, Y-shaped sound barrier is planned
to be constructed between the transformer and the east residential building.

The sound attenuation value in the sound shadow area behind the barrier can be expressed by the
following formula.

$$\Delta L = \begin{cases} 
  20 \times \lg \frac{\sqrt{2\pi N}}{\tanh \sqrt{2\pi N}} \text{dB} + 5 \text{dB}, & N > 0 \\
  5 \text{dB}, & N = 0 \\
  20 \times \lg \frac{\sqrt{2\pi N}}{\tanh \sqrt{2\pi N}} \text{dB} + 5 \text{dB}, & 0 > N > -0.2 \\
  0, & N \leq -0.2 
\end{cases}$$

Where N is the Fresnel number. When there is a sound barrier between the transformer and the
residential building, the noise propagation path is shown in Figure 4. Because the wall of the main
control building reflects the transformer noise, the reflection effect needs to be considered when
calculating the sound attenuation of the sound barrier. A is the original transformer sound source, and B
is regarded as the virtual sound source which is a mirror image of the sound source A. The virtual sound
source B is used to calculate the attenuation of the reflected sound. Set l1 as the distance from the sound
source to the reflection wall (l1 = AH = BH = KL = 4 m), l2 as the distance from the sound source A to
the sound barrier (l2 = LG = 6 m), l3 as the distance from the sound barrier to the residential building
(l3 = GF = 32 m), l4 = CD, l5 = BD, l6 = BC, l7 = AB, l8 = AC. Due to the sound barrier’s special Y
shape, the equivalent height of the sound barrier needs to be calculated. For the original sound source
A, the equivalent height of the sound barrier is h1 (h1 = CG); for the virtual sound source B, the
equivalent height of the sound barrier is h2 (h2 = EG). The height of the sound source is h3 (h3 = 1 m),
and h4 is the height of the east residential building (h4 = 42 m). The $\alpha$ is the angle between the upper
part of the Y-shaped sound barrier and the vertical line ($\angle \alpha = 45^\circ$). For the sound source A, the Fresnel
number is NA (NA = 2 (AC + CD – AD) / $\lambda$); for the virtual sound source B, the Fresnel number is NA
(NA = 2 (BE + ED – BD) / $\lambda$). In order to prevent transformer noise from affecting residents, the
attenuation at point D at 250 Hz, 500 Hz, and 1000 Hz must be greater than 1.6 dB, 10.4 dB, and 0.8
dB, respectively.
Assume that the vertical part of the sound barrier is GI = 14.5 m and the upper part is IJ = 1.5 m. After calculation, for the original sound source A, the equivalent height of the sound barrier is h1 = 18.68 m; for the virtual sound source B, the equivalent height of the sound barrier is h2 = 16.75 m. The Fresnel numbers and sound attenuation at point D are shown in Table 5 and Figure 5.

![Figure 4. Noise propagation path](image)

Table 5. Fresnel numbers and sound attenuation.

| Frequency / Hz | Original sound source A | Virtual sound source B |
|---------------|-------------------------|------------------------|
|               | Fresnel numbers | Sound attenuation | Fresnel numbers | Sound attenuation |
| 31.5          | 0.438            | 10.027                | 0.040            | 5.686              |
| 63            | 0.876            | 12.567                | 0.080            | 6.302              |
| 125           | 1.739            | 15.407                | 0.158            | 7.355              |
| 250           | 3.477            | 18.395                | 0.317            | 9.022              |
| 500           | 6.954            | 21.404                | 0.633            | 11.318             |
| 1000          | 13.908           | 24.415                | 1.266            | 14.069             |
| 2000          | 27.816           | 27.425                | 2.532            | 17.023             |
| 4000          | 55.633           | 30.435                | 5.065            | 20.028             |
| 8000          | 111.266          | 33.445                | 10.130           | 23.038             |

![Figure 5. Comparison of sound attenuation and noise reduction](image)

Finally, the noise reduction program is determined. A sound barrier between the transformer and east residential building should be constructed, connecting both ends with the outer wall of the main control building.
building, as shown in Figure 6. The height of the vertical part of the sound barrier is 14.5 m; the upper part is a Y-shaped sound insulation board with a length of 1.5 m. The lowest 0-1 m height is the ventilation muffler. In addition, two sound insulation doors are installed for maintenance.

Figure 6. Sound barrier simulation diagram.

4.3. Sound insulation board
A kind of sound insulation board is designed, which has an excellent sound insulation effect on the noise below 1000 Hz. The sound transmission loss of this board with thickness of 60 mm at different frequency is shown in Table 6.

Table 6. Sound transmission loss.

| Frequency / Hz | 125  | 250  | 500  | 1000 |
|----------------|------|------|------|------|
| Sound transmission loss / dB | 35.1 | 31.8 | 37.8 | 43.3 |

5. On-site measurement after noise control
After noise control, the noise level at substation boundary decreased significantly, and it is less than the limit. The noise reduction at all the measuring points in the daytime is more than 7 dB(A), as is shown in Table 7. The measuring point 16 with maximum boundary noise level in the night-time is reduced from 55.9 dB(A) to 46.7 dB(A), and the noise reduction is 9.2 dB(A).

Table 7. Noise level at substation boundary after noise control.

| Measuring points | $L_{Aeq}$ / dB(A) | Evaluations | $L_{Aeq}$ / dB(A) | Evaluations |
|------------------|------------------|-------------|------------------|-------------|
|                  | Daytime [a]      | Limit [c]   |                  | Night-time [a, b] | Limit [c]   | Evaluations |
| 13               | before 57.5      | 60          | Qualified        | after 49.3    | 60          | Qualified   |
|                  | after 49.3       | 60          | Qualified        |              |             |             |
| 14               | before 58.5      | 60          | Qualified        | after 48.9    | 60          | < Emission limit 50 | Qualified   |
|                  | after 48.9       | 60          | Qualified        |              |             |             |
| 15               | before 59.7      | 60          | Qualified        | after 48.3    | 60          | < Emission limit 50 | Not-qualified   |
|                  | after 48.3       | 60          | Qualified        |              |             |             |
| 16               | before 58.6      | 60          | Qualified        | after 48.4    | 60          | < Emission limit 50 | Not-qualified   |
|                  | after 48.4       | 60          | Qualified        |              |             |             |
| 17               | before 56.5      | 60          | Qualified        | after 48.8    | 60          | < Emission limit 50 | Not-qualified   |
|                  | after 48.8       | 60          | Qualified        |              |             |             |
| 18               | before 59.7      | 60          | Qualified        | after 50.8    | 60          | 44.0         | Qualified |
|                  | after 50.8       | 60          | Qualified        |              |             |             |
| 19               | before 60.0      | 60          | Qualified        | after 48.4    | 60          | < Emission limit 50 | Qualified   |
|                  | after 48.4       | 60          | Qualified        |              |             |             |
| 20               | before 58.9      | 60          | Qualified        | after 48.7    | 60          | 45.6         | Qualified |
|                  | after 48.7       | 60          | Qualified        |              |             |             |
The result has been corrected using background noise value via standard of GB 12348-2008. When the difference between the noise measurement value and the background noise value is less than 3dB, and the difference between the noise measurement value and the emission limit of the measured noise source is less than or equal to 4dB, "< Emission limit" should be used to represent the result according to standard of HJ 706-2014. According to standard of GB 12348-2008.

It can be seen from Table 8 that the noise level in the noise-sensitive area has been evidently reduced after the noise control, and it meets the limit of the standard of GB 3096-2008 in the daytime and nighttime. The noise level at measuring point 21 in the nighttime is reduced from 56.3 dB (A) to 44.5 dB(A), and the noise reduction is 11.8 dB(A).

Table 8. Noise level in the noise-sensitive area after noise control.

| Measuring points | $L_{Aeq}$ / dB(A) | Evaluations | $L_{Aeq}$ / dB(A) | Evaluations |
|------------------|-------------------|-------------|-------------------|-------------|
|                  | Daytime Limit | | Night-time Limit | |
| 21 before        | 57.5              | Qualified   | 47.6              | Qualified   |
| after            | 49.3              | Qualified   | < Emission limit  | 50          |
| 22 before        | 58.5              | Qualified   | 51.5              | 50          |
| after            | 48.9              | Qualified   | < Emission limit  | 50          |

[a] According to standard of GB 3096-2008.

6. Conclusion
This paper proposes a method of sound barrier design for substation noise control. After noise control, the noise level meets the limit of the standard of GB 12348-2008 at substation boundary, and meets the limit of standard of GB 3096-2008 in the noise-sensitive area in the daytime and nighttime respectively.

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