Noise Control of An Indoor Substation

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Abstract. Noise measurement on transformers, substation boundary and noise-sensitive buildings of a 110kV indoor substation was carried out. The 1/3-octave band spectrums in different areas were analyzed, and was found that the transformer noise affects the substation boundary and noise-sensitive buildings. Taking ventilation and noise reduction into account, this paper proposes a noise control program. With this program executed, the noise reduction of north side of substation boundary is more than 9 dB in the daytime, more than 14 dB in the nighttime while it is 7.9 dB in the daytime, 8.6 dB in the nighttime in the residential building on the west side of the substation.

1. Introduction

Power substations are important hubs for the transmission of electric energy, and are essential in modern society. With the development of urbanization, the residents are consuming more power. Moreover, more and more substations are constructed in densely populated areas, bringing about environmental pollution issues. The transformer in the substation emits noise around the clock during operation, which can disturb residents near the substation and threaten the residents’ physical and mental health. In recent years, it has been prevalent that residents who live near the substations complain that their life is greatly interfered by the noise generated by substations. The problem of transformer noise pollution has become prominent. The substation must meet relevant environmental standards and not interfere with the work and life of residents nearby during electric energy supply.

The substations are divided into three types, indoor type, semi indoor type and outdoor type. Due to the shortage of urban land, an increasing number of urban indoor substations was selected to save land resources. Although transformer room can insulate the sound to some extent, noise emitted by transformers may still transmit to the noise-sensitive buildings due to short distance between them. New indoor substations are designed with noise reduction function, and a layer of sound-absorbing material is added to the wall surface of the transformer room. However, the old transformer room in indoor substation has no noise reduction measures, and its noise pollution is particularly serious due to long operation life. Ming studied the vibration and noise characteristics of the transformer when running at 50 Hz AC through experiments and prediction simulations, showing that the frequency of transformer noise is mainly at 100 Hz and its first few multiples, containing low-frequency components [1]. Low-frequency noise has a wide range of sources in modern cities, including vehicles, aircraft, machinery, compressors, ventilation and air-conditioning. Studies have shown that low-frequency noise can cause hearing impairment, adverse speech intelligibility and other health effects, such as changing blood pressure and heart rate, endocrine disorder, psychological and mental harm [2-5]. Ordinary noise control measures have decreasing efficacy in reducing low-frequency noise compared with other noise.
Therefore, effective transformer noise treatments are urgently needed for substations in densely populated areas. Xu installed perforated sound-absorbing materials on the wall and noise elimination gallery at the air inlet in a 110kV indoor substation, which reduced the noise of substation boundary from 54 dB(A) to 47 dB(A), with a decrease of 7 dB(A) [6]. Wang put forward a low-noise indoor substation design method that modified layout and sound-absorbing materials can reduce the noise in noise-sensitive area by 6.6 dB(A) [7]. Aiming at the noise control of indoor substation, this paper proposes a method to solve the noise pollution problem.

2. Problem description

One 110kV indoor substation was constructed in 1989 with two 40MVA transformers. The specific parameters of the transformer are shown in Table 1. According to on-site survey, there is a kindergarten on the north of the substation, a residential building on the west side, and road on the east or south side. The teachers and students of kindergarten complain that the transformer noise interferes with learning and working. The distance between teaching building of kindergarten and the transformer is 45.0 m, and 17.9 m between the residential building on the west side and the transformer. A 12.0 m high building is built in the substation, and two transformers are located in the transformer room which is in the north of this building. There is a wall with a height of 5.0 m in the middle of the transformer room to separate the two transformers. Thin iron plates and ventilation shutters at a height of 0-5.5 m, and ventilation shutters at a height of 7.1-9.6 m were installed on the front of the transformer room, as seen in Fig. 1. Four glass windows were placed on the left of transformer room as well as the right side. However, the sound absorption and insulation properties of iron plates, ventilation shutters and glass windows are poor.

| Parameters               | #1 transformer | #2 transformer |
|--------------------------|----------------|----------------|
| Year of manufacturing    | 1989           | 1989           |
| Type                     | SFZ7-40000/110 | SFZ7-40000/110 |
| Manufacturer             | Changzhou transformer factory | Changzhou transformer factory |
| Cooling mode             | ONAN/ONAF     | ONAN/ONAF     |
| Rated capacity / MVA     | 40             | 40             |

Figure 1. Appearance of transformer room.
3. On-site measurement before noise control

3.1. Meteorological conditions and instruments

| Time          | Wind speed (m/s) | Weather |
|---------------|------------------|---------|
| 15:00—16:30   | 1.1              | Sunny   |
| 22:30—23:30   | 1.2              | Sunny   |

Meteorological conditions for this measurement are listed in Table 2. The noise measurement needs to be conducted in the weather without rain, snow, thunder and lightning, and the wind speed is less than 5 m/s.

3.2. Standard limits

According to the Chinese standard of GB 12348-2008 [8], the noise emission limits of the substation boundary during daytime(06:00-22:00) and nighttime(22:00-06:00) are 60 dB(A) and 50 dB(A) respectively; the noise limits of noise-sensitive area during daytime and nighttime are also 60 dB(A) and 50 dB(A) respectively in terms of in terms of GB 3096-2008 [9].

3.3. Measurement method

The measurement of transformer noise should be carried out on the prescribed contour, which is 0.3 m away from the principal radiating surface. The principal radiating surface refers to a chord contour line around the transformer, which is a surface formed by moving vertically from the top of the cover to the bottom. Transformer noise should be carried out on the prescribed contour which is at the height of 1/3 of the transformer tank, and the measuring points (#1 to #8) are shown in Fig. 2. Both transformers were in operation in the whole process of measurement.

The measuring points of substation boundary noise are 1.0 m outside the enclosing wall and 0.5 m higher than the enclosing wall. The specific measuring points (#9 to #15) are illustrated in Fig. 2. Substation boundary noise should be measured in the daytime and nighttime, as well as the background noise. The measured noise level needs to be corrected based on Chinese standards of GB 12348-2008 and HJ 706-2014 [10].}

![Figure 2. Location map of measuring points.](image-url)
one digit. If $\Delta L_2 \leq 4$ dB, qualitative result is given according to Table 4 and evaluated as being qualified. If $\Delta L_2 \geq 5$ dB, measured noise level can not be evaluated, and the substation boundary noise and background noise should be remeasured.

**Table 3.** Correction value ($\Delta L_1 < 3$ dB).

| $\Delta L_1$ / dB | 3 | 4~5 | 6~10 |
|-------------------|---|-----|------|
| Correction value  / dB | −3 | −2 | −1 |

**Table 4.** Correction method (3 dB $\leq \Delta L_1 \leq 10$ dB).

| $\Delta L_2$ / dB | Result after correcting | Evaluations |
|-------------------|-------------------------|-------------|
| $\leq 4$           | < limit                 | Quilified   |
| $\geq 5$           | Can not be evaluated    |             |

For the measurement of noise-sensitive buildings, the measuring points (#16 and #17) are arranged on the second floor of the kindergarten and the second floor of the residential building on the west side, as shown in Fig. 2.

### 3.4. Measurement results

The noise level of these two transformers are expressed in Table 5. The noise level of #1 transformer is between 74.2 dB(A) and 76.2 dB(A), and the #2 transformer is between 73.5 dB(A) and 75.4 dB(A). Fig. 3 is the 1/3-octave band spectrum of these two transformers. The sound pressure level of #1 transformer at 100 Hz, 200 Hz is prominent, and the prominent frequency of #2 transformer is 100 Hz, 200 Hz, 315 Hz, and 500 Hz.

**Table 5.** Measurement result of two transformers noise before control.

| Equipment | Measuring points | $L_{Aeq}$ / dB |
|-----------|-----------------|----------------|
| #1 transformer | #1            | 74.2           |
|            | #2            | 75.5           |
|            | #3            | 76.2           |
|            | #4            | 75.2           |
| #2 transformer | #5            | 73.8           |
|            | #6            | 73.5           |
|            | #7            | 75.4           |
|            | #8            | 74.9           |

![Figure 3. 1/3-octave band spectrum of two transformers.](image)

As shown in Table 6, the A-weighted sound pressure level of substation boundary is between 54.4 dB(A) and 64.6 dB(A) in the daytime and between 46.4 dB(A) and 63.2 dB(A) in the nighttime. The
noise level of #9 and #10 measuring points exceed the standard limits which are 60 dB(A) and 50 dB(A) in the daytime and nighttime; while #11, #12, #14 and #15 measuring points only exceed the nighttime limit of 50 dB(A).

The measurement results of noise-sensitive buildings are revealed in Table 7. The noise level in the residential building on the west side of substation in the nighttime has reached 56.1 dB(A), exceeding the limit of 50 dB(A). Because it was not allowed to enter the kindergarten when collecting data, the noise level of kindergarten was unknown before noise control.

Table 6. Measurement result of boundary noise before controlling.

| Measuring points | Daytime, $L_{Aeq}$ / dB | Evaluations | Nighttime, $L_{Aeq}$ / dB | Evaluations |
|------------------|-------------------------|-------------|--------------------------|-------------|
|                  | Measuring value | Corrected value | Limit | Measuring value | Corrected value | Limit |
| #9               | 64.6          | 64.6          | 60     | 62.3          | 62.3          | 50   |
| #10              | 61.5          | 61.5          | 60     | 63.2          | 63.2          | 50   |
| #11              | 57.8          | 56.8          | 60     | 54.1          | 53.1          | 50   |
| #12              | 58.2          | 57.2          | 60     | 51.8          | 50.8          | 50   |
| #13              | 56.0          | 55.0          | 60     | 48.4          | 46.4          | 50   |
| #14              | 55.4          | 54.4          | 60     | 51.1          | 50.1          | 50   |
| #15              | 57.9          | 56.9          | 60     | 52.7          | 51.7          | 50   |

Background value 49.1 44.3

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

Table 7. Measurement results of noise-sensitive buildings before controlling.

| Measuring points | Daytime, $L_{Aeq}$ / dB | Evaluations | Nighttime, $L_{Aeq}$ / dB | Evaluations |
|------------------|-------------------------|-------------|--------------------------|-------------|
|                  |                        | Limit |       | Limit |
| #16              | Not measured            | 60    | Not measured             | 50   |
| #17              | 58.0                    | 60    | 56.1                      | 50   |

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

3.5. Cause analysis of exceeding the limits

Although the transformers are placed indoors, the sound absorption and insulation effect of the iron plates and the ventilation shutters on front of the transformer room and the glass windows on the left and right of the transformer room are not ideal. As a consequence, transformers can continuously emit noise into noise-sensitive buildings, disturbing residents continuously. Since the main control building owns shielding effect, the noise emitted by transformers does not have a significant impact on the south boundary. As the outside of east boundary is road and there is a certain distance between the residential area on the east side and the transformer, the east residential area is not been affected evidently. Transformer causes vibration and generates noise in operating condition. There are two possible pathways for the noise to transmit to noise-sensitive buildings, via structure and air. As shown in Fig. 4, the edge of the substation is lawn, blocking the structural transmission through the floor. It is determined that the transformer noise is transmitted to the noise-sensitive buildings through the air.
4. Analysis of noise characteristics of substation boundary and noise-sensitive building
Transformer noise is prominent at 100 Hz, 200 Hz, 315 Hz, and 500 Hz on the basis of 1/3-octave band spectrum. Fig. 5(a) shows the sound pressure level of the substation boundary is prominent at 100 Hz and 500 Hz, compared with the 1/3-octave band spectrum [Fig. 5(c)] of background noise, demonstrating that the substation boundary noise is affected by the noise emission of the transformer. Fig. 5(b) shows 100 Hz and 200 Hz is the prominent frequency in residential building on the west side compared with Fig. 5(c), demonstrating transformers are the significant sound sources.

5. Design of noise reduction program
In order to reduce the noise level of substation boundary to be less than 60 dB(A) and 50 dB(A) during daytime and nighttime respectively, the following program is designed, as shown in Fig. 6.

(1) As shown in Fig. 6, the existing iron plates and ventilation shutters at a height of 0-5.5 m on the front of the transformer room are removed and replaced with a sound barrier, which includes H-shaped steel, sound absorption and insulation boards, ventilation mufflers, and sound insulation doors.

(2) The existing ventilation shutters at a height of 7.1-9.6 m on the front of the transformer room are removed and replaced with ventilation mufflers.

(3) Eight glass windows on the left and right of the transformer room are removed and replaced with ventilation mufflers.

Figure 4. Noise transmission pathways.

Figure 5. 1/3-octave band spectrums in different measuring point in the nighttime.
6. On-site measurement after noise control

After the installation of noise reduction materials is completed with reference to the design program, the noise level of the substation is measured, and the scene after noise control is shown in Fig. 7.

![Figure 6. Design drawing of noise control of substation.](image)

![Figure 7. The scene after noise control.](image)

| Measuring points | Daytime, $L_{Aeq}$/dB | Nighttime, $L_{Aeq}$/dB | Evaluations |
|------------------|-----------------------|------------------------|-------------|
|                  | Measured value | Emission value $[^a]$ | Limit $[^b]$ | Measured value | Emission value $[^a]$ | Limit $[^b]$ |
| #9               | before          | 64.6                   | 64.6          | 60           | 62.3                   | 62.3          | 50 | Not-qualified |
|                  | after           | 51.7                   | 50.7          | 60           | 50.2                   | 48.2          | 50 | Qualified     |
| #10              | before          | 61.5                   | 61.5          | 60           | 63.2                   | 63.2          | 50 | Not-qualified |
|                  | after           | 53.5                   | 52.5          | 60           | 49.7                   | 47.7          | 50 | Qualified     |
| #11              | before          | 57.8                   | 56.8          | 60           | 54.1                   | 53.1          | 50 | Not-qualified |
|                  | after           | 47.8                   | < limit       | 60           | 46.5                   | < limit       | 50 | Qualified     |
| #12              | before          | 58.2                   | 57.2          | 60           | 51.8                   | 50.8          | 50 | Not-qualified |
|                  | after           | 48.2                   | < limit       | 60           | 45.6                   | < limit       | 50 | Qualified     |
| #13              | before          | 56.0                   | 55.0          | 60           | 48.4                   | 46.4          | 50 | Qualified     |
|                  | after           | 51.0                   | 50.0          | 60           | 48.4                   | 45.4          | 50 | Qualified     |
| #14              | before          | 55.4                   | 54.4          | 60           | 51.1                   | 50.1          | 50 | Not-qualified |
|                  | after           | 54.2                   | 53.2          | 60           | 48.6                   | 46.6          | 50 | Qualified     |
| #15              | before          | 57.9                   | 56.9          | 60           | 52.7                   | 51.7          | 50 | Not-qualified |
|                  | after           | 53.7                   | 52.7          | 60           | 48.1                   | 45.1          | 50 | Qualified     |
| Background value | before          | 49.1                   | 44.3          | /            | 45.3                   | 45.1          | /  |
|                  | after           | 45.3                   | 45.3          | /            |                        |               | /  |

$[^a]$ According to standard of GB 12348-2008. $[^b]$ Measurement result has been corrected using background noise value based on standard of GB 12348-2008. $[^c]$ If $\Delta L_1 < 3$ dB and $\Delta L_2 \leq 4$ dB, the emission value is recorded as “< limit” based on standard of HJ 706-2014.

As shown in Table 8, A-weighted sound pressure level of substation boundary has decreased significantly after noise control, and it is lower than the limits of 60 dB(A) and 50 dB(A) in the daytime and nighttime respectively. The problem that the emission of transformer noise at the boundary exceeds
the standard has been solved. The highest noise level at #9 and #10 measuring points decreased from 64.6 dB(A) and 61.5 dB(A) to 50.7 dB(A) and 52.5 dB(A) in the daytime, respectively, with noise reduction of more than 9 dB; decreased from 62.3 dB(A) and 63.2 dB(A) to 48.2 dB(A) and 47.7 dB(A) in the nighttime, with noise reduction of more than 14 dB.

The noise level of kindergarten (#16 measuring point) in the daytime and nighttime is 44.2 dB(A) and 42.8 dB(A) after reforming respectively, and the noise level of residential building (#17 measuring point) on the west side of substation decreases from 58.0 dB(A) and 56.1 dB(A) to 50.1 dB(A) and 47.5 dB(A) in the daytime and nighttime, with noise reduction of 7.9 dB in the daytime and 8.6 dB in the nighttime, as shown in Table 9.

Table 9. Measurement results of noise-sensitive buildings after controlling.

| Measuring points | Evaluations | $L_{Aeq}$/dB |
|------------------|-------------|--------------|
|                  | Daytime | Limit [a] | Nighttime | Limit [a] |
| Before #16       | Not measured | 60 | Not measured | 50 |
| After #16        | 44.2 | 60 | 42.8 | 50 | Qualified |
| Before #17       | 58.0 | 60 | 56.1 | 50 | Not-qualified |
| After #17        | 50.1 | 60 | 47.5 | 50 | Qualified |

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

7. Conclusion
This paper presents a method on noise control of indoor substation, where noise reduction, ventilation and heat dissipation are all taken into consideration. The on-site measurement results indicate that the sound barrier assembled by the ventilation mufflers and the sound absorption and insulation boards on front of the transformer room has a significant suppression effect on the transmission of airborne noise. After the completion of noise control, the noise at substation boundary and the noise at the noise-sensitive building meet the specification from Chinese standards of GB 12348-2008 and GB 3096-2008.

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