Analysis and control of ventilation noise reduction for box-type transformer in urban area

Fayuan Wu¹*, Yaqiong Chen², Xiaolei Liu¹, and Jinhui Tang¹

¹ State Grid Jiangxi Electric Power Research Institute, Nanchang, Jiangxi, 330096, CN
² Jiangxi Ganneng Co. Ltd. Fengcheng Phase II power plant, Fengcheng, Jiangxi, 331100, CN

Corresponding author’s e-mail: 894586743@qq.com

Abstract: Noise generated by outdoor box transformer in the working process has a certain impact on the production and life of the surrounding residents. Combining with the current situation of box transformer in 10kV urban area of a residential district, the paper analyses the problems and causes of noise transmission and control. According to the characteristics of noise sources and transmission ways of substation, the paper puts forward and implements ventilation, heat dissipation and sound insulation cover to reduce noise, improve room temperature and ventilation effect, and compares with the effect of noise control before and after modification. The result shows that the effect of modification is obvious and the noise at boundary of box transformer meets the national standard.

1. Introduction
Due to the continuous expansion of city scale, the substations in urban power network area have to go deep into the load centers of urban central areas and residential districts. Because it is often very close to residential buildings, the low-frequency noise generated by its operation is transmitted to the residential rooms through the attenuation of short distance air, thus affecting the normal life of residents. With the improvement of people's awareness of environmental protection, people's requirements for their living environment are gradually raised. As a result, the noise problem of box transformer has increasingly become the focus of attention of all parties.

The outdoor box transformer of a power supply company Oriental Paris District #1 box transformer is situated in the greening bushes of the residential area. There is a dry-type transformer with rated capacity of 800 kVA. The cooling mode is ONAN. The noise generated by the operation of the box has a certain impact on the surrounding households. It has been complained many times by the surrounding households, and the problem needs to be solved urgently.

2. Problems and causes of problems

2.1. Problems

2.1.1. On-side testing. Based on the surrounding environment of the residential area where the box transformer is located, the location of 1.0 m away from the box transformer and 1.2 m in height are tested. Each azimuth is equipped with a measuring point. Considering the influence of road noise on daytime noise, only night noise is tested. Figure 1 is the site layout of #1 box transformer in the Oriental Paris District, and the noise monitoring points are shown in Figure 2.
2.1.2. Analysis of results. According to the 《Acoustic Environmental Quality Standard》, 《Environmental Noise Emission Standard for Industrial Enterprises》 and the delimitation of the acoustic environmental functional zones by the local environmental protection bureau, Level two should be implemented for the control of noise. The specific monitoring results of noise outside protective cover of #1 box transformer in Oriental Paris District are shown in Table 1.

| Measuring point number | Night monitoring results | Standard values dB(A) |
|------------------------|--------------------------|-----------------------|
|                        | Testing values dB(A)     |                       |
| 1                      | 57.1                     | 50                    |
| 2                      | 54.8                     | 50                    |
| 3                      | 53.6                     | 50                    |
| 4                      | 51.5                     | 50                    |

The monitoring results show that the nocturnal emission of #1 box of variable noise in Oriental Paris exceeds the two categories of emission standard values of GB12348-2008, and the maximum exceeding standard is 7 dB (A). Therefore, noise control is needed.

2.2. Cause Analysis

2.2.1. Inadequate noise reduction capability. From Figure 1, we can see the structure of #1 box transformer. The protective cover is made of foam sandwich panel structure with foam thickness of about 50mm. Both sides are fixed by 0.4 ~ 0.5mm rigid steel plate. Steel plate is used to separate transformer from low and high voltage cabinet. Because of the prevention and control of porous foam between two layers of steel plates, sound waves cannot enter the foam, and the sound waves are reflected by the inner steel plates, so the foam does not produce sound absorption. When the inner steel plate is deformed under the action of sound waves, the foam is equivalent to "spring", which can suppress the vibration of the plate, will compress the foam, distort and deform the inner material of the foam, and consume part of the sound energy.

The main noise source of the box transformer is the low frequency noise, especially 100-500Hz. The foam sandwich panels have poor stiffness and low frequency noise penetration, so it is difficult to prevent low frequency noise. It is estimated to be only 5-7dB (A). At the same time, both sides of the foam sandwich panels are galvanized steel sheets. The noise will be repeatedly reflected and superimposed in the indoor environment, resulting in reverberation noise, and the sound pressure level of the main transformer chamber will increase to 3 ~ 5dB (A).
2.2.2. *The ventilation design is unreasonable and the sound leakage is serious.* The ventilation system of #1 box transformer in Oriental Paris District adopts open louver ventilation window and the door is not tightly sealed, which can easily lead to sound leakage, and the area of sound leakage is about 2-3% of the total surface area of the box. Acoustic theory points out that the gap of sound insulation structure directly affects the sound insulation performance. The influence of holes and slots is mainly determined by the ratio of their size to acoustic wavelength. If the size of the hole is larger than the wavelength of sound wave, the sound energy through the hole can be approximately considered to be proportional to the area of the hole. According to the formula for calculating the comprehensive sound insulation capacity of composite structure, for an ideal sound insulation wall ($\tau = 0$), if there are holes in the wall with an area of 1/100, the total sound insulation capacity of the wall can only reach 20 dB. Therefore, the sound transmission through cracks has a significant impact on the overall sound insulation performance of composite walls.

In addition, the louvers are located on the same side, resulting in "short circuit" of air distribution, insufficient use of ventilation channels, and increase the risk of sound leakage.

3. **Overall Design and Improvement of Outdoor Box Transformer Sound Insulation Cover**

3.1. **Design Ideas of Box Transformer Sound Insulation Cover**

According to the theory of slot structure and ventilation and heat dissipation structure, the sound insulation cover design of box transformer comprehensively considers sound absorption, isolation and vibration reduction. The four sides around the sound insulation cover and the sound insulation doors all need to adopt the composite sound absorption and insulation cover plate to ensure the sound insulation of the cover body, and the staggered joint structure is adopted for the combination of the overhaul door and the cover body; the top of the sound insulation cover adopts the variable cavity micro-perforation structure combined with the sound insulation composite roof plate to make full use of the roof space; the air inlet and outlet passages adopt different structures to silence the sound. The structure achieves the silence of the holes. Through the vibration isolation at the bottom of the transformer body, the influence of the vibration of the transformer body on the overall noise radiation of the sound insulation cover is reduced. At the same time, in order to reduce the reverberation noise of the transformer room properly, the typical design of the compartment partitions is designed as a porous sound absorption board structure. In order to improve the comprehensive noise reduction effect of each component's sound insulation, the principle of "sound energy transmission equivalent" is introduced to realize the rational optimization design of the sound insulation cover.

3.2. **Optimum Design and Analysis of Comprehensive Noise Reduction for Box Transformer Sound Insulation Cover**

Combining with the theoretical formula of sound insulation capacity of each component of sound insulation hood, the noise reduction calculation of #1 box in Oriental Paris Residential Area is carried out, and the performance parameters of each component are optimized and calculated.

In view of the noise characteristics of transformer, the noise absorption and insulation composite structure is adopted in the design of the noise insulation cover panel, whose sound insulation capacity is calculated to be 40 dB; on the basis of the original design shape, the top of the sound insulation cover adopts the variable cavity micro-perforation structure combined with the sound insulation composite roof panel, and the calculation value of the sound insulation capacity is 40 dB; on the design of the sound insulation door, the sound insulation capacity is 30 dB. The muffling capacity is 25 dB, the muffling capacity of exhaust muffler is 25 dB, and the designed sound insulation capacity of hole and slot seals is 10 dB. The integrated noise reduction of the combined noise shield is calculated as shown in the table below.
Table 3. Parameters design of integrated noise reduction for combined sound insulation hood.

| Component name                        | Calculated area (m²) | Net area (m²) | Percents of total area | Component sound insulation | $\tau=10^{-\frac{R}{10}}$ | $\tau \times S^a$ |
|---------------------------------------|----------------------|---------------|------------------------|---------------------------|---------------------------|------------------|
| Compound sound absorption and insulation cover plate | 22.66               | 22.66         | 47.34%                 | 40                        | 0.0001                   | 0.0023           |
| Roof                                  | 9.5                  | 9.5           | 19.85%                 | 40                        | 0.0001                   | 0.0010           |
| Sound insulation door                 | 13.39                | 13.39         | 27.97%                 | 30                        | 0.001                    | 0.0134           |
| Inlet muffler                         | 1.25                 | 1.25          | 2.61%                  | 20                        | 0.01                     | 0.0125           |
| Exhaust muffler                       | 0.56                 | 0.56          | 1.04%                  | 25                        | 0.0032                   | 0.0018           |
| Gap                                   | 0.5                  | 0.5           |                         | 10                        | 0.1                      | 0.0500           |
| Total                                 | /                    | 47.86         | 100.00%                | /                         | /                        | 0.0809           |
| Comprehensive sound insulation(dB)    | /                    | /             | /                      | /                         | /                        | 27.7             |

From the calculation results in Table 3, it can be concluded that the overall noise reduction is 7 dB higher than the theoretical noise insulation, reaching 27.7 dB, even though there are 1.04% cracks in the sound insulation cover, due to the acoustic design of the slot structure and the ventilation noise elimination structure.

3.3. Performance Test of Box Transformer Sound Insulation Cover

3.3.1 Testing Process.
Testing standards: Acoustic Insulation Performance Measurement of Acoustic Insulation Covers Part 2: On-site Measurement (for Acceptance and Verification).
Testing instruments: Dodecahedron standard sound source; BK2270 precision level meter.
Testing conditions: the designed and manufactured sound insulation cover is placed in the middle of a 300 M² workshop, with an open surroundings and a background noise of about 25 dB; the sound source is supported on the ground by a tripod with a distance of 1.2 m from the ground and a sound source signal of 20 kHz white noise; the microphone is 1.2 m from the ground and 1 m from the four sides of the sound insulation cover. The position of the microphone remains unchanged when the cover and no sound insulation cover are used. Figure 3 are the plots of the field and measurement points for the performance test of the box transformer noise shield.

![Figure 3](image-url)
Figure 3. Layout of test points for performance test of box transformer sound insulation cover
3.3.2 Test results. The results of sound source and test points are shown in Table 4.

Table 4. Test results of total sound insulation of box transformer noise shield.

| Location of measuring points | Sound pressure level without sound insulation (dB) | Sound pressure level with sound insulation (dB) | Loss value (dB) |
|-----------------------------|-----------------------------------------------|-----------------------------------------------|-----------------|
|                             |                                               | 1    | 2    | 3    | average value |                                |
| 1                           | 68.1                                          | 67.1 | 67.9 | 67.7 | 22.3           |                                |
| 2                           | 57.2                                          | 54.7 | 53.2 | 55.0 | 35.0           |                                |
| 3                           | 58.1                                          | 58.3 | 58.0 | 58.1 | 31.9           |                                |
| 4                           | 70.7                                          | 71.3 | 71.4 | 71.1 | 18.9           |                                |
| Average                     | 90                                            | 63   |      |      | 27             |                                |

3.4. Implementation of Noise Reduction

In order to further reduce the emission noise of box transformer, the structure of ventilation, heat dissipation and sound insulation cover of box transformer is designed and implemented according to the calculation. The specific implementation is shown in Figure 4.

4 Effect and analysis after transformation

Figure 4. #1 box transformer noise reduction field implementation diagram.

Figure 5. Comparisons of daytime noise and night levels before and after reconstruction.
From figure 5, it can be seen that the average daytime noise of outdoor is reduced from the highest 57.4 dB (A) to the highest 47.6 dB (A), and the nocturnal noise is reduced from the highest 57.1 dB (A) to the highest 43.8 dB (A). The comprehensive noise reduction effect is more than 10 dB (A). The results are excellent, and the emission values meet the national standard of functional area 1.

From Figure 6, it can be seen that the noise value of the transformer room and the outside of the sound insulation cover decreases to varying degrees in each frequency band, especially in the low frequency band. Reverberation noise in transformer room is reduced by 4-6 dB (A) due to the use of double-layer micro-orifice plate structure. At the same time, the noise of the enclosure is up to the standard, and the disturbance behavior of low frequency noise is also controlled.

![Figure 6. Comparisons of night noise level of each frequency section outside the transformer room at night before and after reconstruction](image)

5 Conclusion

The noise reduction transformation of outdoor box transformer should be based on the specific conditions of noise characteristics, noise level, ventilation requirements of main transformer room and surrounding environment, and take into account the sound sources and transmission routes, combined with the actual situation.

The field measured data and comparative analysis prove that the noise reduction effect of the ventilation, heat dissipation and sound insulation hood is obvious, and the phenomenon of low frequency noise disturbing people is successfully solved. The noise not only meets the standard, but also does not disturb people, thus demonstrating the image of green and harmonious power grid.

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