Analysis of Noise Pollution and Control of 110kV Transformer Substations

Xiaopeng Fan*, Wenyuan Tang, Li Li, Hongming He, Zhuanglei Zou, Cunren Ma

1Electric Power Research Institute of Guangdong Power Grid Limited Liability Corporation, Guangzhou, China
2Unionville high school, Unionville, Canada

*Corresponding author e-mail: 283128493@qq.com

Abstract. An example of noise control for the north gate of Quzhou110kV transformer substation. Based on the survey, measurement of the sound sources, and also result analysis, the acoustic enclosure with natural ventilation is designed by using the space around the main transformer and considering the heat dissipation of the main transformer, and also the maintenance requirement in the future. With dedicated acoustic modeling, the Cadna/A software prediction results show that the main transformer noise radiation to the measuring points of factory boundary near the residential area and residential area in the out of factory boundary decrease more than 12dB after the proposed noise control structure. After the superposition of background noise, the noise level of factory boundary and the sensitive point in the out of factory boundary reach to the 1 class sound functional area standard.

1. Introduction

With the development of society and improvement of living standards, the adverse impact on people resulted by noise pollution is increasing [1-3]. Especially the low-frequency noise radiation of substation is playing a more significant role, so it has become the main complaint of surrounding residents. Many substations must be moved to urban centers from suburbs, which is resulted by the rising electricity consumption because of rapid development of the city. Therefore, controlling the substation noise is an urgent problem [4-5]. This paper takes north gate of Quzhou110kV substation as an example. At the beginning, the work including site survey and monitoring was carried out, and the data of substation noise was analyzed comprehensively. After that, a feasible noise control scheme was proposed, as well as the predicted analysis about substation noise control effects.

2. The feature of north gate of Quzhou110kV substation

Nearby this substation, residential area is in the east, and the residential area under construction is in the south, whereas office buildings are in the west and north. The nearest distance from the factory boundary to the east side of the residential buildings is about 7 meters. The surrounding environment of the factory is shown in Figure 1.
There are two 110kV transformers (2×40 MVA) in the factory, located in the center of substation. The building containing switch and control rooms is in the north of factory. In addition, four arc suppression coil chambers are in the southwest position. The situation is illustrated in Figure 2. Two main transformers’ parameters are expressed in Table 1.

**Figure 1.** Schematic diagram of environment around the factory and measurement points

**Figure 2.** Schematic diagram of factory layout
Table 1. Parameters of main transformers

| 1# Main transformer | 2# Main transformer |
|---------------------|---------------------|
| **Type** | Type | **Cooling mode** | **Cooling mode** |
| SZ9-40000/110 | SZ9-40000/110 | ONAN | ONAN |
| L1480AC200- | L1480AC200- | | |
| L1250AC95 | L1325AC140 | | |
| /L75AC35 | /L75AC35 | | |
| **Insulation Level** | **Insulation Level** | **No-load loss** | **No-load loss** |
| LI480AC200- | LI480AC200- | 23.06 kW | 27.82 kW |
| LI250AC95 | LI325AC140 | | |
| /LI75AC35 | /L75AC35 | | |
| **Equipment kind** | **Equipment kind** | **Load loss** | **Load loss** |
| Outdoor type | Outdoor type | 148.4 kW | - |
| **Rated frequency** | **Rated frequency** | **Upper oil tank** | **Upper oil tank** |
| 50 Hz | 50 Hz | weight | weight |
| **Phase number** | **Phase number** | **Active part mass** | **Active part mass** |
| Three phases | Three phases | 35500 kg | 32200 kg |
| **Rated capacity** | **Rated capacity** | **Oil weight** | **Oil weight** |
| 40000 kVA | 40000 kVA | 16235 kg | 18800 kg |
| **Rated voltage** | **Rated voltage** | **Shipping weight** | **Shipping weight** |
| 110/10.5 kV | 110/10.5 kV | 51850 kg | 55400 kg |
| **Connection group** | **Connection group** | **Symbols** | **Symbols** |
| YN.d11 | YN.d11 | | |
| **Temperature rise** | **Temperature rise** | **Manufacturing code** | **Manufacturing code** |
| of top-oil | of top-oil | A010945 | 090-0025 |
| Impedance | Impedance | | |
| voltage | voltage | | |
| 12.48% | 12.48% | | |
| **No-load current** | **No-load current** | **Manufacturer** | **Manufacturer** |
| 0.09% | 0.20% | Nanjing power transformer factory | Shandong Luneng Mount. Tai Electric Equipment Co.,Ltd |

3. Noise analysis in north gate of Quzhou 110kV substation

3.1. Noise-measurement experiment

To analyze noise in north gate of Quzhou 110kV substation, site survey was started firstly. Secondly, noise was measured on site via AWA6291 Noise Signal Real-Time Analyzer, when both main transformers were running at full load. Site survey was shown in Figure 3; on-site measurement point diagram could be found in Figure 1; measurement result could be seen in Table 2.
Figure 3. Site-survey diagram of transformer (left: main transformer, right: transformer radiator)

| Measuring point | 1# | 2# | 3# | 4# | 5# | 6# | 7# | 8# | 9# | 10# | 11# |
|-----------------|----|----|----|----|----|----|----|----|----|-----|-----|
| 12.5            | 57.3 | 53.0 | 50.9 | 55.0 | 63.3 | 60.5 | 62.7 | 61.9 | 59.8 | 51.7 | 58.5 |
| 16              | 59.6 | 54.0 | 51.6 | 56.1 | 58.3 | 60.7 | 59.7 | 59.0 | 58.1 | 50.4 | 56.5 |
| 20              | 56.1 | 58.3 | 50.5 | 51.8 | 57.8 | 57.8 | 57.6 | 57.4 | 58.1 | 50.5 | 66.1 |
| 25              | 59.2 | 58.9 | 53.1 | 52.8 | 56.7 | 55.7 | 56.5 | 58.6 | 54.6 | 56.8 | 61.3 |
| 31.5            | 57.1 | 54.1 | 52.4 | 48.9 | 50.9 | 53.6 | 56.7 | 55.5 | 52.7 | 62.5 | 52.5 |
| 40              | 57.4 | 50.7 | 48.2 | 46.8 | 50.2 | 50.3 | 51.1 | 53.6 | 50.6 | 61.3 | 56.1 |
| 50              | 52.7 | 51.5 | 49.5 | 50.9 | 50.4 | 48.8 | 50.1 | 50.8 | 51.1 | 60.5 | 51.6 |
| 63              | 53.2 | 51.8 | 49.2 | 47.9 | 49.5 | 47.8 | 55.2 | 47.6 | 47.4 | 55.9 | 45.6 |
| 80              | 53.8 | 49.4 | 45.6 | 45.5 | 45.6 | 50.3 | 51.7 | 46.9 | 48.2 | 49.6 | 41.2 |
| 100             | 62.9 | 65.3 | 61.3 | 63.6 | 58.7 | 65.2 | 69.9 | 59.7 | 57.7 | 62.4 | 50.0 |
| 125             | 48.8 | 50.7 | 46.1 | 48.6 | 46.9 | 49.5 | 53.0 | 46.9 | 44.9 | 47.3 | 42.5 |
| 160             | 47.3 | 46.8 | 43.9 | 44.9 | 45.3 | 45.3 | 48.3 | 44.6 | 43.8 | 41.9 | 41.9 |
| 200             | 63.7 | 57.0 | 61.8 | 58.3 | 54.2 | 58.4 | 59.5 | 50.6 | 50.9 | 41.8 | 44.5 |
| 250             | 49.4 | 48.1 | 45.8 | 46.8 | 43.2 | 45.8 | 49.4 | 46.6 | 43.5 | 41.6 | 38.4 |
| 315             | 58.1 | 66.7 | 47.5 | 62.3 | 48.9 | 50.5 | 57.0 | 59.0 | 49.5 | 45.5 | 45.3 |
| 400             | 63.0 | 56.3 | 60.7 | 57.5 | 58.2 | 53.1 | 59.8 | 55.0 | 49.7 | 41.9 | 41.1 |
| 500             | 63.2 | 64.3 | 56.5 | 66.3 | 56.3 | 51.4 | 49.0 | 56.6 | 50.5 | 44.3 | 40.9 |
| 630             | 69.6 | 63.1 | 64.8 | 59.1 | 60.2 | 62.3 | 53.6 | 61.8 | 50.9 | 45.0 | 51.0 |
| 800             | 52.5 | 49.9 | 48.2 | 49.2 | 48.8 | 49.4 | 52.9 | 50.6 | 46.6 | 42.3 | 37.0 |
| 1000            | 45.8 | 45.2 | 48.6 | 451 | 39.7 | 41.1 | 45.9 | 44.2 | 43.5 | 42.2 | 36.0 |
| 1250            | 40.8 | 41.4 | 41.5 | 39.9 | 38.0 | 37.8 | 44.3 | 39.2 | 41.2 | 41.5 | 34.5 |
| 1600            | 38.5 | 39.7 | 39.6 | 35.5 | 36.3 | 35.8 | 40.4 | 35.8 | 38.9 | 40.6 | 32.8 |
| 2000            | 35.9 | 35.4 | 37.0 | 34.4 | 34.7 | 36.0 | 38.4 | 32.9 | 38.1 | 37.3 | 31.4 |
| 2500            | 33.6 | 32.9 | 37.3 | 32.6 | 32.5 | 39.3 | 36.9 | 34.8 | 38.3 | 34.3 | 31.4 |
| 3150            | 31.1 | 30.3 | 34.8 | 31.5 | 30.6 | 38.4 | 35.7 | 34.0 | 38.2 | 31.3 | 31.7 |
| 4000            | 32.0 | 30.0 | 36.1 | 35.0 | 33.6 | 36.4 | 35.1 | 33.4 | 35.9 | 38.6 | 31.3 |
| 5000            | 30.0 | 27.3 | 30.1 | 29.3 | 26.9 | 32.8 | 28.1 | 25.3 | 30.7 | 26.8 | 30.6 |
| 6300            | 24.4 | 23.6 | 37.5 | 28.7 | 24.4 | 30.0 | 23.6 | 21.8 | 25.7 | 23.4 | 29.5 |
| 8000            | 22.0 | 22.0 | 37.2 | 27.4 | 22.7 | 28.5 | 22.0 | 20.8 | 23.3 | 21.7 | 28.1 |
| 10000           | 21.2 | 20.4 | 35.1 | 26.8 | 20.4 | 25.6 | 19.5 | 19.6 | 21.1 | 19.5 | 26.3 |
| 12000           | 21.4 | 17.9 | 32.6 | 26.1 | 18.9 | 22.9 | 19.3 | 19.1 | 19.9 | 18.1 | 23.9 |
| 16000           | 20.3 | 19.1 | 27.3 | 22.3 | 18.1 | 22.9 | 25.9 | 21.5 | 24.1 | 17.3 | 21.4 |
| $L_A$           | 69.1 | 66.0 | 64.5 | 65.1 | 60.8 | 61.6 | 60.4 | 62.2 | 55.0 | 52.1 | 51.2 |
| $L_C$           | 73.0 | 71.8 | 69.0 | 70.3 | 66.3 | 68.6 | 71.3 | 67.4 | 63.1 | 66.9 | 63.7 |
| $L_Z$           | 73.5 | 72.2 | 69.4 | 70.7 | 68.8 | 70.1 | 72.4 | 69.5 | 66.2 | 68.7 | 68.9 |
3.2. Noise analysis

After analyzing the result of site survey and monitoring, it can be discovered that the key noise sources are these two transformers leading to the noise at factory boundary and excessive noise of sensitive position outside factory boundary. It should be noted that the principal noise radiated by transformers is in low and middle frequency. The noise of factory boundary meets the requirement that it should be less than 55 dB during the daytime, however it doesn’t meet the requirement during the night due to being more than 45 dB. The noise of nearest residential area outside factory boundary in the east of substation also meets the requirement that it should be less than 55 dB during the daytime, while more than 45 dB during the night.

An analytical result of 1/3 octave spectrum measured at various point indicates that various multiplex frequency bands above 1250 Hz are less than 41 dB. On the contrary, every frequency band not more than 1250 Hz is deemed to be the management focus.

4. Noise control schemes

4.1. Noise control standards

Referring to “environmental quality standard for noise” (GB3096-2008) and “emission standard for industrial enterprises noise at boundary” (GB12348-2008), the emission limit for boundary noise in north gate of Quzhou110kV substation is that the equivalent sound level should be not more than 55 dB during the daytime, while it should be not more than 45 dB during the night. In the meanwhile, the equivalent sound level in residential area outside boundary should be not more than 55 dB during the daytime, while it should be not more than 45 dB during the night.

4.2. Noise control targets

After controlling the noise in substation, the noise emission at factory boundary should satisfy class 1 standard when the equipment is in normal operation. That means the equivalent sound level should be not more than 55 dB during the daytime, while it should be not more than 45 dB during the night. At the same time, the acoustic environment of every sensitive point outside boundary should reach the standard of class 1. In other words, the equivalent sound level should be not more than 55 dB during the daytime, while it should be not more than 45 dB during the night.

4.3. Noise control measures

Based on the investigation, measurement and analysis of the on-site sound source, it is determined that the chief objects of the noise control are these two main transformers. Consulting management targets and considering the safety requirements in substation, the following noise control schemes are proposed.

(1) General ideas

It could be found that the noise in substation came from the main transformers, and the low-frequency noise was the major part from the investigation. Main transformers in substation are special in terms of security, so reducing the noise of main transformers themselves will not be considered. In conclusion, a detachable, ventilated naturally and heat-dissipation sound insulation cover has been designed when the surrounding space, heat dissipation and maintenance of main transformers have been taken into account. The structure of this sound insulation cover is illustrated in Figure 4.
(2) Control measures

A sound absorption and insulation barrier is installed around the main transformer along the edge of the accident oil pool. The fundamental structure consists various layers (from the outside to the inside, 1.5 mm galvanized sheet, 80 mm and 60 kg/m³ mineral wool filling layer, glass cloth and 0.5 mm perforated aluminum panel (perforation > 25%). Inside the insulation board the keelson is made of hot dip galvanized and U-shaped steel. Barrier below 0.2 m is made from brick wall plastered on double sides.

This sound insulation cover is mainly formed by noise-elimination louvers and sound absorption and insulation boards. Moreover, a soundproof door for maintenance will be established in the east or west side facing substation gate. The overall thickness of noise-elimination louver is 0.5 m. The noise-elimination louver piece has a Y shape with a thickness of 100 mm and a piece spacing of 100 mm. The basic structure consists of 3 layers-0.5 mm perforated aluminum panel (perforation > 25%), a mineral wool layer surrounded by glass cloth and 0.5 mm perforated aluminum panel (perforation > 25%). The bulk density of mineral wool layer is more than 60 kg/m³.

In order to prevent rain or snow piles on the top of the sound insulation cover, the specific lean of sound insulation board is required. Additionally, heat dissipation of this cover is a problem which is needed to be considered so a muffler made up from pieces should be installed on the top of sound insulation cover with size of 1.5m×1.5m×1.6m (Length×width×height). The basic structure of muffler piece which distance between two adjacent ones and thickness are 100 mm, is the same as noise-elimination louver installed in air inlet.

Figure 4 Schematic diagram of sound insulation cover (left: vertical view; right: frontal cutaway vie)
About incoming and outgoing lines of the main transformer, the incoming and outgoing pipes are uniformly arranged like the incoming and outgoing lines of switch wall. And then a sealant is used to fill the gap between the line pipe and sound insulation cover. All the metal parts in the sound insulation cover must be connected in series with copper wires and well-earthing to prevent static electricity. An explosion-proof lamp is installed in the sound insulation cover for illuminating when routine maintenance is started. To maintain the appearance, the external of this cover is painted and the paint color is decided by the factory. Furthermore, the maintenance of substation in the future is an essential item, so the noise-elimination louver mentioned above and the sound absorption and insulation barrier facing the main control building in north are detachable.

5. Prediction and analysis of noise control effect
Based on acoustic modeling, the noise reduction effect is predicted by Cadna/A software. The predicted and measured value before and after controlling the noise at each measuring point is showed in Table 3. Background noise for example traffic noise, influences the measurement process, so a certain error between predicted value and measured value is occurring. However, this error is acceptable. Only the noise of main transformer is thought to contribute to every measurement point in the prediction process. Therefore, the controlling outcome should be evaluated with the noise insertion loss before and after controlling. The measurement data in this area before and after controlling is shown in Table 3.

| Predicted point | 1# | 2# | 3# | 4# | 5# | 6# | 7# | 8# | 9# | 10# | 11# |
|-----------------|----|----|----|----|----|----|----|----|----|-----|-----|
| Measured value  | 69.1| 66.0| 64.5| 65.1| 60.8| 61.6| 60.4| 62.2| 55.0| 52.1| 51.2 |
| Before controlling | 67.9| 67.4| 66.3| 67.6| 63.6| 62.6| 63.3| 64.1| 55.0| 51.1| 49.3 |
| After controlling | 50.1| 49.3| 48.4| 49.5| 45.2| 45.1| 44.7| 46.7| 39.6| 36.9| 37.2 |
| Insertion loss   | 17.8| 18.1| 17.9| 18.1| 18.4| 17.5| 18.6| 17.4| 15.4| 14.2| 12.1 |

The prediction results show that the noise at different measurement point radiated from the main transformer can be reduced by more than 12 dB after controlling, and the noise level of factory boundary and sensitive point reaches the acoustic function region standard of Class 1 under the condition that other surrounding noise sources are unchanged.

Acknowledgments
This work was supported by the science and technology project of China Southern Power Grid (No. GDKJXM20180152).

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