Research on the Effect of Plant Boundary Conditions on Noise Attenuation in UHV Substations

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Abstract. Accurately analyzing the influence of the terrain environment of the plant boundary on noise transmission and attenuation can not only give guidance for the substation site selection and station layout optimization, but also provide theoretical basis for noise abatement after the substation has been put into operation. In this paper, by applying sound level meters to test the sound pressure of the main equipment in the substation and the noise around the plant boundary, the noise characteristics of main transformers and shunt reactors, as well as the noise distribution around the plant boundary were analyzed, thus concluding that the noise at the plant boundary is mostly derived from the main equipment within the substation. While taking the layout of the Zhebei UHV Substation as an example, this paper chose the SoundPLAN software to simulate and calculate the noise attenuation law under seven terrain conditions outside the plant boundary, and finally such a proposition as the low-lying terrain and the raised hilly terrain can best interrupt the noise transmission was made. The conclusions of this paper can provide a theoretical reference for site selection of new substations and optimizing the terrain structures of substations in operation.

1. Introduction

The rapid and continuous economic development and the increasingly improved people's living standard boost the demand for electricity. To this end, long-distance and large-capacity UHV transmission is imperative to optimize the distribution of resources through "west-east power transmission and nationwide power network building". However, in recent years, with the UHV projects being put into operation one after another, the impacts of electric field, magnetic field, radio interference and noise brought about therefrom have become a major concern of the public, and have also gained the attention of the State Grid Corporation and relevant environmental protection departments.

The special research results and on-site environmental measurement in UHV projects showed that the power frequency electric field, power frequency magnetic field, noise, etc. within the environmental impact assessment range of UHV substations and transmission lines basically meet the requirements of national and industrial standards[¹]. However, the acoustic environment impact of substation noise on noise-sensitive buildings surrounding the plant boundary is still prominent. In addition, since substation noise control zones have been canceled by the Ministry of Ecology and
Environment, the emission of up-to-standard ambient noise along the plant boundary becomes more difficult to realized.

Considering the above-mentioned situation, on the one hand, the State Grid Corporation proactively carries out research on how to reduce noise emitted from the main equipment, thereby alleviating the sound radiation intensity of sound sources; on the other hand, based on accurate noise prediction, the locations of main equipment in the substations and the terrain conditions of the plant boundary are considered in the planning and layout of UHV substations to comprehensively control the impact of noise transmission. Based on the noise measurement and analysis results of UHV substations, by adopting the SoundPLAN software to simulate the noise distribution under seven different terrain conditions outside the plant boundary of UHV Zhebei Substation, this paper analyzed the law of noise attenuation under different terrain conditions, and proposed two types of terrains that can effectively resist noise, providing a theoretical reference for locating new substations and optimizing the terrain structures of substations in operation.

2. Noise measurement in UHV substations

During the noise measurement at the UHV Zhebei Substation, the noise of main equipment and the plant boundary noise [2, 3, 4] are measured with the 2250 sound level meter manufactured by B&K, a Danish company. The noise of main equipment is measured two times around the main equipment at 1/3 height of the shunt reactor and 2/3 height of the main transformer, respectively. The sound level meter is located 1 m from the transformer perpendicularly, with an interval of 0.5 m between the two measuring points, and the sound power level and spectral characteristics [5, 6] of the main equipment are thus obtained.

![Figure 1: Spectrum of the Transformer's A-weighted Sound Power Level](image1)

![Figure 2: Spectrum of the Shunt Reactor's A-weighted Sound Power Level](image2)

Fig. 1 shows the spectrum distribution of the transformer's A-weighted sound power level. Based on the data in the figure, the transformer's total A-weighted sound power level is calculated to be 102.7 dB(A), which is large in the frequency band from 50 Hz to 800 Hz, is especially concentrated between the central frequencies of 100 Hz to 200 Hz [7, 8]. Fig. 2 shows the spectrum distribution of the sound power level of the shunt reactor. The sound power level of the shunt reactor is calculated to be 96.8 dB(A) according to the data in the figure. In the frequency range of 50 Hz to 1000 Hz, the A-weighted sound power level reaches its maximum value that is very close to the total sound power level of the reactor, i.e. 96.4dB(A) on the 100Hz-centered octave frequency band, which indicates that the 100Hz spectral component is the main energy of the shunt reactor noise [9,10,11,12].

In order to measure the noise of the plant boundary, 137 measuring points are set along the plant boundary of the UHV Zhebei Substation at an interval of 10 m between measuring points. The receiving points are arranged 1 m away from the plant boundary and 0.5 m above the wall. The measuring conditions are shown in Fig. 3, and the measuring results of noise along the plant boundary according to the terrain conditions in Fig. 3 are shown in Fig. 4. Analysis according to the figures
shows that among the 137 measuring points along the plant boundary, the noise level of shunt reactors is relatively high, especially at the corner of the plant boundary adjacent to the Anlan high-voltage shunt reactor and less than 10 m from the shunt reactors, where the measured sound pressure level is about 60 dB(A). In addition, the noise levels of the Anlan high-voltage shunt reactor and 1# main transformer along the plant boundary are also high, especially at the corner of the plant boundary near 1# main transformer, where the measured sound pressure level is about 58 dB (A), and the sound pressure levels at the other two sides of the plant boundary are less than 50 dB (A).

Upon calculation based on the measured data in Fig. 4, the average sound pressure level along the plant boundary of Zhebei Substation is 54.1 dB(A), whose spectrum components are shown in Fig. 5. The analysis shows that the main energy of the plant boundary noise, which is concentrated at 100 Hz and its multiple frequency components, has a sound pressure level of 44.74 dB(A) at 100 Hz. The sound pressure level energy at 200 Hz, 300 Hz, 400 Hz is also relatively concentrated.

The average sound pressure level spectrum of the plant boundary noise shown in Fig. 5 is almost the same as the frequency component of the main transformers shown in Fig. 1 and that of the shunt reactors shown in Fig. 2. The frequency components at 100 Hz are the most distributed, followed by 200 Hz, 300 Hz, 400 Hz, etc., which shows that the noise at the station boundary is mainly from the main equipment. At UHV substations in operation, the main transformers are normally located in a central position of the substations to keep a certain distance from the plant boundary, thus attenuating the noise from the transformers along the plant boundary to some extent. However, shunt reactors, as the reactive-load compensation equipment in the electric power system, are usually installed on the outgoing line side of EHV and UHV substations to compensate for the increase of the power.
frequency voltage caused by the capacitance effect of compensated lines \[13, 14\]. When a reactor's capacity is large, the noise made by the reactor is large and causes large impact on noise-sensitive buildings outside the substation, which is a key factor affecting the realization of up-to-standard emission of ambient noise along the plant boundary of substations. In the event that the layout of the main equipment in substations cannot be modified, and noise prediction indicates a large impact of noise on the noise-sensitive buildings outside the plant boundary, comprehensive measures can be taken to attenuate the noise according to the terrain conditions around the plant boundary.

3. Noise prediction and analysis under different terrain conditions around the plant boundary

Before the construction of a substation, the feasibility study and environmental impact assessment during site selection shall be carried out. First, the station site should be properly selected according to the terrain conditions and the acoustic environment of corresponding functional zones, which is then optimized by comprehensively considering the plant boundary conditions, ingoing and outgoing line conditions, the layout of the main equipment, etc. In this paper, with the UHV Zhebei Substation as an example, the SoundPLAN software is used to calculate and analyze the attenuation law of noise transmission outside the plant boundary under seven terrain conditions.

According to the calculated sound power levels of the main equipment as shown in Fig. 1 and Fig. 2, the source intensity of the input main transformers is obtained as 102.7 dB(A), and that of shunt reactors is 96.8 dB(A); the wall height of plant boundary is 3 m. Receiving points are arranged on one side with a calculated height of 1.5 m, and start from the plant boundary at an interval of 10 m till 200 m outside the plant boundary \[15, 16\], as shown in Fig. 6. On one side where the receiving points are distributed outside the plant boundary, the terrain conditions are set to be flat ground, upslopes and downslopes, hills, and low-lying ground. Only the impacts of various terrain conditions at the substation sites are considered, while the air absorption and ground absorption during the noise transmission are excluded.

![Figure 6: Calculation Model of Zhebei Substation](image_url)

As shown in Fig. 7, the above-mentioned terrains are categorized into seven models: Terrain 1 is flat ground, Terrain 2 upslope, Terrain 3 downslope, and Terrain 4 and Terrain 5 flat ground or lawn with a certain distance of upslope or downslope, Terrain 6 raised hill and Terrain 7 low-lying ground. Terrain 4 and Terrain 5 are further divided into two subcategories, respectively: Terrain 4a and Terrain 4b, Terrain 5a and Terrain 5b. Within the same range of the plant boundary, Terrain 4b's downslope is steeper than that of Terrain 4a; in the flat area, Terrain 4b is lower than Terrain 4a. As for the Terrain 5, Terrain 5b's upslope is steeper than that of Terrain 5a; in the flat area, Terrain 5b is higher than Terrain 5a. The noise attenuation laws of the seven terrains are calculated in Fig. 8, Fig. 9 and Fig. 10. In order to compare the noise attenuation laws of different terrains, the three calculation results are compared with Terrain 1.

In Fig. 8, Terrain 1 is flat ground outside the station boundary, whose noise attenuation is consistent with the general law that the sound source is attenuated with the distance. Terrain 2 is upslope outside the station boundary, such as the raised hillside or slope surface, whose noise...
The attenuation law is the same as that of Terrain 1, namely increased noise attenuation with the distance; however, due to its raised terrain that causes the receiving points of noise being obviously higher than the plant boundary wall, there is no obstruction during noise transmission and the noise values at the receiving points are significantly higher than the same locations in a flat terrain. Terrain 3 is downslope outside the station boundary, that is, the terrain along the plant boundary is higher than the surrounding terrain. The calculation results show that within the range beyond 100 m, the noise attenuation law is the same as Terrain 1 and Terrain 2, but within a range near the plant boundary, the noise attenuation is very fast, because the downslope makes the noise receiving points lower than the terrain at the same position of Terrain 1, thus "increasing" additionally a height of the boundary wall to effectively resist the noise during the sound transmission.

Fig. 9 shows the noise attenuation laws of Terrain 1, Terrain 4 and Terrain 5: the noise attenuation of Terrain 4 within a range close to the plant boundary is relatively fast, and the attenuation effect is larger when the slope becomes steeper. In a flat area, Terrain 4b is lower than Terrain 4a, thus "increasing" additionally a height of the boundary wall to effectively resist the noise during the sound transmission. As for Terrain 5, within the range close to the plant boundary, due to the raised terrain, the noise receiving points are higher than the plant boundary wall, and the noise value is higher than that of the terrain at the same position on the flat ground; beyond a certain distance of flat ground, the noise attenuation becomes significantly fast, which, on the one hand, is a normal attenuation with distance, and on the other hand, is caused by the raised slope that effectively resists the noise [17].
Fig. 10 shows the noise attenuation laws of Terrain 1, Terrain 6 and Terrain 7. Terrain 6 has hills near the plant boundary. For the side of hills near the plant boundary, the noise receiving points are higher than the boundary wall, and accordingly there is no obstruction during the sound transmission, making the noise values of the receiving points relatively high; but on the other side of the hills, the noise values are rapidly decreased to the background values, which indicates that the raised terrain effectively resist the noise [18]. Terrain 7 has a low-lying ground near the plant boundary, where the terrain is low, and the boundary wall can effectively resist the noise transmission.

4. Analysis of measured data of noise attenuation along the plant boundary

During the noise measurement along the plant boundary of the UHV Zhebei Substation, the noise attenuation is tested outside the plant boundary on the side of shunt reactors and at the plant boundary on the side of the station site entrance. There is a small hill outside the plant boundary on the side of shunt reactors, as shown in Fig. 11, and low-lying ground is distributed at the plant boundary on the side of the station site entrance, as shown in Fig. 12.

![Figure 11: Plant Boundary Conditions on the Side of Shunt Reactors at Zhebei Substation](image1.png)

![Figure 12: Plant Boundary Conditions at the Entrance of Zhebei Substation](image2.png)

The starting point of the noise attenuation test at the two boundaries is 0.5 m above the side wall. According to the actual test conditions, the measuring points are selected in the direction...
perpendicular to the boundary wall. The height of the measuring points is 1.5 m from the ground, and the test results are shown in Table 1.

Table 1: Noise Attenuation outside the Plant Boundary of Zhebei Substation (Unit: dB(A))

| Distance to the plant boundary wall | 0m | 5m | 10m | 15m | 20m | 25m | 30m | 35m | 40m |
|-----------------------------------|----|----|-----|-----|-----|-----|-----|-----|-----|
| On the side of shunt reactors      | 56.6 | 58.5 | 56.8 | 54.1 | 53.6 | 49.3 | 48.7 | 46.3 | 46.1 |
| At the station entrance            | 48.2 | 45.7 | 36.1 | 36.3 | 36.3 | 36.3 | 36.5 | 36.5 | 36.4 |

Table 1 shows that the noise value above the boundary wall outside the plant boundary on the side of shunt reactors is 56.6 dB(A). Considering that there is a hill outside the plant boundary, and that the slope near the plant boundary is steep, receiving probes were arranged higher than the boundary wall for noise measurement. The noise value at 5 m from the plant boundary is 58.5 dB(A). Above the hill, the noise test value gradually decreases with the increase of the distance from the plant boundary. The noise value above the boundary wall at the station site entrance is 48.2 dB(A), and the noise value at the location 5 m from the plant boundary is 45.7 dB(A). At the measuring point 10 m from the plant boundary, the terrain abruptly declined by 10 m, and the noise value was rapidly attenuated to the background value [19, 20]. The noise attenuation laws of the two measuring points outside the plant boundary in Table 1 are consistent with Terrain 5 and Terrain 7, respectively, which testifies that the low-lying ground and the raised hilly terrain can most effectively resist the noise during the sound transmission.

5. Conclusions

At present, the UHV substations in operation are all situated in the suburbs, and belong to Category II according to their functional areas of acoustic environment. Based on the noise measurement around the plant boundary, it can be concluded that the main equipment in substations constitute the major sources of noise along the plant boundary. In most cases, main transformers are arranged at the center of the station site, and shunt reactors are laid out near the plant boundary. The noise value near the plant boundary on the side of shunt reactors is significantly higher than that at other locations along the plant boundary. Therefore, out-of-standard noise is often made near the plant boundary on the side of shunt reactors.

Relevant calculation and measurement results show that without considering the air absorption and ground absorption, when the terrain outside the plant boundary is low, the noise there is attenuated most rapidly; when there is a raised hilly terrain outside the plant boundary, the noise value on the side close to the plant boundary is significantly increased because of the receiving points that are higher than the boundary wall, while the noise value is rapidly decreased to the background value on the side of the raised hill far from the plant boundary. Considering that the obstacles outside the boundary wall and the plant boundary can effectively resist the noise during the sound transmission, the forest and buildings can be used as barriers to resist the noise transmission when the terrain outside of the plant boundary is flat.

In order to control the acoustic environmental impact on noise-sensitive buildings around the plant boundary, it is necessary to comprehensively consider the layout of the main equipment at the station and the terrain conditions outside the plant boundary, and make best of the terrain conditions outside the plant boundary, alleviating the discharge impact of substation noise on noise-sensitive buildings around the plant boundary. The conclusions of this paper can provide a theoretical basis for locating new substations and optimizing the terrain structures of the substations in operation.

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References

[1] Wan Baoquan, Xie Huichun, Fan Liang et al. Electromagnetic Environment and Corona Control Measures for UHV Substations [J]. High Voltage Engineering, 2010, 36(1): 109-115.

[2] Zhou Bing, Pei Chunming, Ni Yuan et al. Noise Measurement and Analysis of UHV AC Substations [J]. High Voltage Engineering, 2013, 39(6): 1447-1453.

[3] Hu Jingzhu, Liu Dichen, Liao Qingfen, Yan Yang et al. Analysis of Electromagnetic Vibration Noise of Transformers Based on Finite Element Method [J]. Transactions of China Electrotechnical Society, 2016, 31(15): 81-88.

[4] Hu Jingzhu, Liao Qingfen, Yan Yang, Pei Chunming et al. Noise characteristics analysis and prediction model study of high voltage substations [J]. High Voltage Apparatus, 2017, 53(2): 32-38.

[5] Hu Jingzhu, Liu Dichen, Liao Qingfen, Yan Yang, Liang Shanshan. Electromagnetic Vibration Noise Analysis of Transformer Windings and Core [J]. IET Electric Power Applications, 2016, 10(4): 251-257.

[6] Ni Yuan, Zhou Bing, Wang Yanzhao et al. Noise Calculation of 750 KV Reactor upon Consideration of Magnetostrictive Shrinkage [J]. Smart Grid, 2016, 06(6): 439-448.

[7] Ni Yuan, Zhang Guangzhou, Zhang Xiaowu et al. Noise Evaluation and Treatment of UHV AC Test Base [J]. High Voltage Engineering, 2009, 35(8): 1856-1861.

[8] Sun Tao, Pei Chunming, Hu Jingzhu et al. Noise Source Model and Simulation Analysis of UHV Transformers [J]. High Voltage Engineering, 2014, 40(9): 2750-2756.

[9] Zhou Bing, Song Qian, Ni Yuan, Chen Yucho, Zhang Jiangong. Noise Characteristics and Control of HV Shunt Reactors, High Voltage Engineering, 2016, 42(6): 1819-1826.

[10] Ni Yuan, Zhou Bing, Pei Chunming, Zhai Guoqing. Analysis of Acoustic Interference Characteristics around 1000 kV UHV Shunt Reactors [J]. High Voltage Engineering, 2015, 40(12): 3926-3932.

[11] Ni Yuan, Zhou Bing, Pei Chunming, Liu Zhenhuan. Research on Sound Source Model of UHV Shunt Reactors [J]. Noise and Vibration Control, 2014 (12).

[12] Guan Junjun. Measures for Loss Reduction and Noise Control of HV Shunt Reactors[J]. Electrical Equipment, 2006, 5(12): 15-17.

[13] Qi. Tang, Yuan. Ni, et al., “Low-frequency tonal noise transmission through an acousticalEnclosure,” 12th ICBEN Congress on Noise as a Public Health Problem, Zurich, 18-22 June 2017.

[14] J. Pan, Y. Wang, et al., “Recent Developments in Noise Assessment and Condition Monitoring of Ultra-High-Voltage Power Transmission Systems,” 2016 International Conference on Mechatronics, Control and Automation Engineering, Phuket, 2016. (EI)

[15] Xu Luwen, Xie Hui, Luo Fangfang, Zou Anxin. Comparative Study of Main Influencing Factors on External Sound Field Distribution of Main Transformers - Taking 220 KV Indoor Substation as an Example [J]. Applied Acoustics, 2018,37(3): 378-384.

[16] Xu Luwen, Liu Xiaoling. Research on 3D Spatial Attenuation Model and Algorithm of Environmental Noise in Substations [J]. Proceedings of the CSEE, 2012, 32(13): 175-180.

[17] Li Yongming, Wang Yuqiang, Xu Luwen, Shen Jie et al. Noise Prediction and Simulation Analysis of Substations [J]. Electric Power Construction, 2013, 34(7), 63-67.

[18] Girgis R S, Bernesjo M S, Thomas S, et al. Development of Ultra-Low-Noise Transformer Technology[J]. IEEE Transactions on Power Delivery, 2011, 26(1):228-234.

[19] Jie Pan, Joanna Wang and Ming Jin, Structural vibration of a transformer, the 17th international congress on sound and vibration. 2010.

[20] J. Pan, Y. Wang, et al., “Measurement and analysis of noise and vibration of 1000kV converter transformers,” Proceedings of ICoEV 2015 International Conference on Engineering Vibration, Ljubljana, Slovenia, 2015.