Design of Grounding for High Voltage Test Hall

Tan Ying, Zhou Huili, Cheng Yexin

HIMALAYAL - SHANGHAI - CHINA

Abstract: To ensure the accuracy measurement of the high voltage test and the personal safety, it was demanding that the high voltage test hall should have a very good grounding system. The influence on the grounding resistance of the grounding grids area, the number of the horizontal grounding grids, the distance between the vertical grounding bodies and length of these bodies were systematically compared and analyzed. The idea that a compound grounding system should be installed for the high voltage test hall was pointed out. The horizontal grounding is the main part in the compound grounding system, which combined vertical grounding bodies. The problems and measures which should be noticed in the design of grounding system for the high voltage test hall were also put forward.

Key words: high voltage test hall, grounding resistance, grounding measures

Introduction

The electric design of high voltage test hall is mainly involved in three aspects: grounding, shielding and safety. In terms of high voltage test, good grounding plays a role in sharing the voltage and fixing the potential. The well-designed shielding system of high voltage test hall is vital to smooth operation of high voltage test hall. This paper discusses the design of the main grounding system.

1. Grounding System of High Voltage Test Hall

The 1.4.1 term in the standard for national electric power industry DL 560-1995 Safety Code of Electric Power Industry (High Voltage test part) stipulates that the high voltage test hall should have a very good grounding system to ensure the accuracy measurement of the high voltage test and the personal safety. The grounding resistance should not be higher than 0.5Ω. Table 1 presents part of high voltage test grounding resistance at home and abroad.

Tab. 1 Part of high voltage test grounding resistance at home and abroad
(1) Ensure the reliability and precision of measurement equipment (including display and record instrument)

(2) Prevent the shock wave in the impulse test from generating overvoltage on the low voltage control circuit and other test equipment.

(3) Deter the shock wave in the impulse test from affecting outside the high voltage test room and disturbing the power source.

(4) Reduce the external interference into the minimum.

(5) Provide a shortest and most advantageous discharge channel for the partial discharge.

(6) Provide one-point grounding channel for the impulse test (transient process).

(7) Provide stable and reliable grounding for the power frequency test (steady process).

(8) Provide the reliable equivalent potential for test personnel safety.

The grounding system of high voltage test hall comprises following three parts:

(1) Grounding circuit formed by the six-face Faraday Cage of test hall (east and west test hall, and six-face shielding body of control room).

(2) Main grounding system composed of horizontal grounding belt under the six-face shielding ground of test hall and vertical grounding body.

(3) Auxiliary voltage-sharing round grounding body around the building.

Due to providing shortest and most advantageous discharge channel for the partial discharge, main grounding system should be set within the range of east and west test hall six-face shielding body. How to design the main grounding system? We start by analyzing the grounding resistance formula.

The calculation formula of grounding resistance of vertical grounding electrode is as follows:

$$R = p \ln \left( \frac{4l}{d} \right) / 2\pi l$$

(1)

The calculation formula of grounding resistance of horizontal grounding electrode is in the following:

$$R = p \left[ \ln \left( \frac{P}{h\sigma} \right) + A \right] / 2\pi l$$

(2)

The calculation formula of grounding resistance of compound grounding electrode is as follows:

$$R_n \approx 0.5p / \sqrt{S}$$

(3)

Or

$$R_n \approx p / 4\pi + p / l$$

(4)

In the formula:

$p$— soil resistivity (Ω·m)

$d$—equivalent diameter of grounding electrode (m)

$h$—buried depth (m)

$L$— length of grounding electrode (m)

$A$—shape factor

$S$—horizontal projected area of grounding grids (m²)

$R$—circle radius equal to $S$ (m)

The effect of steel section size of grounding electrode on the
calculation of grounding resistance is so small that we can neglect it. Assume that soil resistivity and buried depth of grounding electrode are known, the formula (1) indicates that vertical grounding electrode must be lengthened to reduce the grounding resistance value of vertical grounding electrode; the formula (2) shows that horizontal grounding electrode must be lengthened or expand the horizontal projected area of grounding grids to reduce the grounding resistance of horizontal grounding electrode; it is clear from formula (3) and (4) that only expanding the horizontal projected area of grounding grids and lengthening vertical grounding electrode can reduce the grounding resistance value of compound grounding electrode.

1.1 Horizontal Grounding Body

1.1.1 Impact of Horizontal Grounding Ring Area on Grounding Resistance

When the grounding grid adopts grounding ring to ground, $p = 40 \, \Omega \cdot m$; $h = 1.2m$; $A = 1.69$; grid width and the equivalent diameter of grounding electrode are different; we can calculate the grounding resistance based on the formula (2). Please refer to Table 2.

Tab. 2 Effect of horizontal grounding ring area on grounding resistance

Based on Table 2, the grounding ring works if the grounding requirement is not high and geological condition is excellent. However, as for the high voltage test hall, it is infeasible. The high voltage test hall in this project is ranked as No. 1 in scale and area after its completion. The results indicate that only adopting the grounding ring cannot meet the requirement of grounding resistance.

It is also clear that the section of grounding body has little impact on the grounding resistance. Hence, the grounding body only needs to meet the requirement of thermal stability, mechanical strength and corrosion resistance.

1.1.2 Effect of Number of Grounding Grids on Grounding Resistance

Area of grounding grids is $48 \times 48 m$, $p = 40 \Omega \cdot m$, $h=1.2$, $d=0.02m$; Table 3 shows that different number of grounding grids correspond to different grounding resistance, which is shown in Table 3.

Tab. 3 Effect of number of grounding grids on grounding resistance
If relevant grounding resistance is taken as cardinal number 1, according to the above calculation method, grounding resistance rate under different grid number is obtained. Use the dot to represent the data on the table and we can draw Figure 1—the effect of number of grounding grids on grounding resistance.

![Fig.1: Effect curve of number of grounding grids on grounding resistance](image)

1.2 Compound Grounding Coordinated with Vertical Grounding Body

The calculation formula of grounding resistance of compound grounding electrode is as follows: In

\[ R_n = \frac{p(0.22 - 0.007 l_1 l_2)(1 + B)}{\sqrt{S}} + \frac{p[l_n (S/hd) - 5B]}{2\pi} \]

\[ B = \frac{1}{(1 + 4.6h/\sqrt{S})} \]

\[ S = l_1 l_2 \]

In the formula:

- \(p\) — soil resistivity (Ω · m)
- \(d\) — steel equivalent diameter (m)
- \(h\) — buried depth (m)
- \(l\) — total length of grounding body (m), including vertical grounding body
- \(l_1\) — horizontal length of grounding grids (m)
- \(l_2\) — horizontal width of grounding grids (m)

1.2.1 Effect of Vertical Grounding Body and Horizontal Grounding Grids Area on Grounding Resistance

When the compound grounding coordinated with short vertical grounding body (focuses on grounding grids. The resistance only reduces by 10%. Obviously, compound grounding should be adopted to reduce grounding resistance of high voltage test hall.
The horizontal grounding grids is set in a certain area; the grounding grids area is $48m \times 48m$, and the round steel vertical grounding electrode is used with $l=6m, d=0.02m, p=40\ \Omega \cdot m$, for the distance between different vertical grounding bodies, the grounding resistance is calculated according to formula (5), the result of which is shown in Table 5.

Based on Table 5, when the distance between vertical grounding bodies is above 2 times length of grounding body, the role in reducing the resistance is great; while the distance between vertical grounding bodies is within 2 times length of grounding body, large quantities of vertical grounding electrodes play little role in reducing the grounding resistance. Because the current will be affected by adjacent grounding electrode flow when the current flows to the ground via grounding electrode. In other words, the current shielding between grounding electrodes will not have a significant impact on resistance reduction no matter how many electrodes are connected to the grounding grids. Therefore, in order to reduce the shielding function of grounding body, the interval of
economic and reasonable vertical grounding bodies should not be less than 2 times of its own length.

1.2.3 Effect of Vertical Grounding Body Length on Grounding Resistance

Assume $p=40 \Omega \cdot m$, $h=1.2m$, $d=1.2m$; grounding grids area is $48 \times 48m$; grounding grids is $12m \times 12m$; when the vertical body adopts $d=0.02m$ round steel vertical grounding electrode, as for different lengths, the grounding resistance can be calculated according to formula (5) and its result is shown in Table 6.

Tab. 6 Effect of distance between vertical grounding bodies on grounding resistance

<table>
<thead>
<tr>
<th>Grounding grids</th>
<th>Cold distance/m</th>
<th>Number of grids</th>
<th>Length of vertical grounding electrode/m</th>
<th>Grounding resistance /Ω</th>
<th>Effect of vertical grounding body on grounding resistance</th>
<th>Ditching quantity/m</th>
<th>Percentage of ditching quantity/%</th>
<th>Quantity of used steel/kg</th>
<th>Percentage of quantity of used steel/%</th>
</tr>
</thead>
<tbody>
<tr>
<td>$48 \times 48$</td>
<td>6</td>
<td>64</td>
<td>3</td>
<td>0.364</td>
<td>-5.4</td>
<td>864</td>
<td>80</td>
<td>2,004.75</td>
<td>71.3</td>
</tr>
<tr>
<td>$48 \times 48$</td>
<td>12</td>
<td>16</td>
<td>3</td>
<td>0.392</td>
<td>1.7</td>
<td>480</td>
<td>100</td>
<td>887.55</td>
<td>31.9</td>
</tr>
<tr>
<td>$48 \times 48$</td>
<td>12</td>
<td>16</td>
<td>6</td>
<td>0.385</td>
<td>100</td>
<td>480</td>
<td>100</td>
<td>1170.30</td>
<td>100</td>
</tr>
<tr>
<td>$48 \times 48$</td>
<td>12</td>
<td>16</td>
<td>6</td>
<td>0.426</td>
<td>10.5</td>
<td>480</td>
<td>-40</td>
<td>566.46</td>
<td>-51.6</td>
</tr>
</tbody>
</table>

From Table 6, when the distance between vertical grounding bodies is 2 times length of grounding body, the grounding resistance of 6m grid and 3m vertical grounding electrode proposal only reduces by 5.4% in contrast with 12 grid and 6m vertical grounding electrode; however, the ditch quantity and steel quantity respectively increase 80% and 71.3%; compared with 24 grid and 6m vertical grounding electrode, although the ditch quantity and used steel quantity reduce by 40% and 51.6%, grounding resistance increases by 10.5%. That is consistent with previous analysis. So it is clear that when the area of horizontal grounding grids is large, the length of vertical grounding electrode has little effect on the grounding resistance. Generally, the length of vertical grounding electrode is 2.5-3m, which is most economic.

Taking skin effect of grounding body into account, deep and long grounding body should be used around the test equipment which needs the current to be diffused quickly. Based on the project condition, adopting non-equal grounding and expanding equipotential area can break the limit of grounding area and make long grounding body play a good role in diffusing the current, providing shortest and most advantageous channel for partial discharge.

2. Measures of Some High Voltage Test Hall Grounding

The high voltage test building covers $4857m^2$. The high voltage test hall is one-story building and is divided into east area and west area. The wast test hall is $27m \times 54m \times 21m$ while east test hall is $44m \times 54m \times 34.8m$. The total building area is $3897m^2$. North of east and west test halls is used as capacitive room and equipment shed; south of east and west test halls is three-layer control room, debugging
room and office. According to the geological drilling report, the soil resistivity is 22Ω·m. Owing to many factors such as seasonal coefficient in the design, the soil resistivity p=40Ω·m to conduct the design calculation. The owner requires the grounding resistance R < 0.25Ω. The interior wall of high voltage test hall, roof steel plate and double plate grid in the floor constitute grounding circuit formed by six-face shielding Faraday Cage; the independent six faces shielding body grounding circuit is composed of interior wall of control room, roof and ground steel. The six-face shielding body and main grounding system are connected with main grounding grid through one fixed grounding well and 11 active grounding wells.

The main grounding system adopts 12m ×12m grid; the number of grids is 16; 2-3 balancing rings with short distance are set around according to actual condition; the outer margin of grounding grids is closed; each corner of the outer margin is arc-shaped; the radius of the arc should be greater than 1/2 of balancing voltage belt distance; the place where people often go and leave is laid with asphalt or two "hat brim shaped" balancing belts connected with grounding grids are set under the ground. A certain amount of 3m length Ø 20mm vertical grounding electrode are set around; 6m length Ø 20mm vertical grounding electrode is set between grounding well of equipment discharge and fixed grounding well of one-point grounding; the distance of vertical grounding electrode is 12m; the section of horizontal grounding body is 50mm × 5mm; the compound of long and short vertical grounding electrode forms pyramid-shaped three-dimension space. The main grounding system adopts copper-clad steel.

The grounding resistance is 0.22Ω through calculation. That conforms to the requirement of grounding resistance owners.

3. Issues Needed to Pay Attention to in the Design of High Voltage Test Hall Grounding

The grounding of high voltage test hall is greatly different from that of general industrial buildings and power plants. So its distinctiveness needs attention during the design.

(1) The grounding circuit is formed by six-face shielding Faraday Cage, which is composed of test hall interior wall, top steel sheet and double-layer steel grid; the inner wall of the control room, top roof and ground steel comprise independent six-face shielding grounding circuit. The impulse test (transient process) requires one-point grounding.

(2) Main grounding grid of high voltage test hall should adopt compound grounding mode coordinated with vertical grounding body. Expand the area of horizontal grounding grid as large as possible. The number of main grounding grids should be less than 16.

(3) The distance between vertical grounding bodies should be greater than two times of its length. The length of vertical grounding is
between 2.5m and 3m. The long and deep vertical grounding body is only applicable to discharge point of the equipment and enlarged potential area in order to reduce the resistance.

(4) The main grounding grid is separated from Faraday Cage by means of insulated materials. Except one-point grounding place, any equipment and fitting have to be connected to one grounding.

(5) The impulse test (transient process) requires the method of one-point grounding; there is certain distance between discharge point and one-point earthing point. Thereby, the discharge point is led to one-point grounding point via shortest path and enlarge the grounding wire section to reduce the resistance of the grounding wire.

(6) The high voltage test hall has two kinds of discharge tests: low current and high voltage or low voltage and high current. According to technical requirement, the thermal stability should be calibrated for grounding system.

(7) Two grounding terminals at each grounding well have reliable electric connection with main grounding grids and steel plate of Faraday Cage. The two grounding terminals of active grounding well adopt feasible connection knife.

(8) The buried grounding body should adopt the same material to prevent ionization in the soil from eroding the grounding body because of different materials. To reduce the contact resistance between the surface of grounding body and the soil, copper-clad steel grounding body is recommended.

(9) If the Faraday Cage of high voltage test hall serves as down-lead, the Faraday Cage should be insulated with building foundation. In the rainy weather, test operation is prohibited and all connection knives of active grounding wells are in the "closed" position at the same time, making Faraday Cage in multiple points grounding.

(10) Measures of reducing step voltage should be taken around the Faraday Cage and entrance; the margin of horizontal grounding ring should close and the corner should have a certain arc.

(11) Except high resistance area, the resistance reducing agent should be used with caution as a main method to reduce the resistance. The effect reduces quickly in the low resistance area. The agent does not play a role in the large grounding grids. The penetration degree of agent is far lower than equivalent radius of grounding grids. The application of agent cannot increase the area of grounding grids.

4. Conclusions

After calculating grounding resistance of high voltage test hall grounding system in the paper, compound grounding mode coordinated with vertical and horizontal grounding is recommended for the grounding of high voltage test hall.
REFERENCES


