Simulation Study on Propagation Characteristics of Optical Signal of Point Discharge in GIS

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Abstract. With the development of the power system, gas insulated switchgear (GIS) is a commonly used module in power system at present. However, in the process of design, manufacturing, transportation and installation, it is inevitable to have various failures, causing serious consequences. At present, partial discharge detection has become an effective way to judge whether failures exist in GIS, especially optical detection method which is developing rapidly. The process of partial discharge will be accompanied by the emission of light signals. By detecting the light signal emitted by the partial discharge, the occurrence of the partial discharge can be effectively detected. Therefore, the propagation characteristics of the optical signal generated by light in GIS will be studied in this paper, and study the relationship between the position of light and data by TracePro, providing a reference for the layout of optical sensors. It is of great significance to the effective detection of partial discharge.

1. Introduction
In recent years, due to the good development of the national economy, our country has greater demand for electrical energy and higher requirements for power supply security. By November 2018, the State Grid has completed 8 AC and 10 DC UHV power transmission projects. Another 4 AC and 2 DC UHV transmission projects are under construction. The length of completed and approved UHV project lines reaches 33,500 kilometers, with a transforming (converting) capacity of more than 340 million kVA(kW).

In the construction of high-voltage power grids, GIS has been widely used in power systems due to its compact structure, flexible configuration, convenient installation, and long maintenance intervals. However, the design, manufacturing, transportation, and installation processes may produce insulation defects and then cause GIS failure[1]. It will affect the upstream and downstream power facilities associated with it, and may even cause large-scale power outages and safety accidents.

Therefore, during the operation, it is of great significance to be able to effectively detect and accurately locate the partial discharge inside the GIS. In addition to the currently used ultrasonic detection methods and UHF detection methods[2-5], optical detection method with stronger anti-interference performance has become a new detection method[6-9].

In this paper, TracePro is used to carry out simulation experiments, simulating the situation where there is a spot-shaped power supply inside the GIS. Set the power source at different positions in the cavity, collect and analyze the data on detection surfaces and detection points, and study the propagation characteristics of the optical signal generated by the power source then provide a reference for the layout of optical sensors.
2. GIS modeling

2.1. GIS body structure
Simplify and model the actual GIS body structure to get the model shown in Figure 1. The left part of the picture is the external style of the model, there are components such as ball stud, connecting high-voltage pole, upper cover, side cover, vent plug and lower cover from top to bottom. The right part shows the interior behind the shell.

The inner height of body is 300mm, the inner radius is 90mm, and the wall thickness is 5mm. The interior fill defaults to air with a refractive index of 1. The surface material of the body is selected from polished and oxidized medium smooth aluminum, with an absorption coefficient of 30%, a specular reflection coefficient of 20%, and a diffuse reflection coefficient of 50%. The diffuse reflection model is a bidirectional reflection distribution function (BRDF) [10].

![Figure 1. GIS body simulation model structure](image)

2.2. Power supply setting
The discharge part is composed of a cone electrode connecting pole, a disk electrode and a discharge source, as shown in Figure 2. The spot-shaped power supply is set as a sphere with a radius of 1mm, which is located at the tip of the needle, and plays the role of simulating the actual GIS internal insulation defect discharge.

It should be noted that the optical power parameters of the simulated light source model are different from the actual partial discharge. Although the relative irradiance cannot explain the actual size of the irradiance value, its change trend can reflect the actual change trend and help summarize the law.

![Figure 2. Partial discharge simulation structure](image)
2.3. Detection surface and detection point setting
In order to obtain the light signal pattern and light flux at different positions during discharge, it is necessary to set detection surfaces and detection points at different distances and angles of the light path. In this paper, the detection surface is a circular surface parallel to the upper and lower cover, which is located on the xy plane, with a radius of 90mm and a thickness of 1mm, that is, each detection surface is a thin cylinder that tends to be flat. As shown in Figure 3, the z-coordinates of the three detection surfaces are 90, 0, and -90, and they are named detection surfaces 1-3.

Three detection points are set on each detection surface, and the angle interval between each two detection points is 120°. Detection points are attached to the inner wall of the cavity. Their normal are perpendicular to the inner wall of the cavity and point to the center of the body. The cross-sectional radius is 10 mm and the thickness is 5 mm. Exploring the difference in the different directions of the light from the discharge power source can get a more accurate light flux change rule. The detection surfaces and points adopt a completely transmissive body mode, which does not cause any absorption or refracting reflection of the light emitted by the power source.

In this paper, in order to distinguish the detection points more clearly, the following naming rules are used: the first number represents the column, x-coordinate of column 1 is 0, y-coordinate is 90; x-coordinate of column 2 is 77.5, y-coordinate is -45; x-coordinate of column 3 is -77.5, y-coordinate is -45. The latter number represents the specific position, which is 1, 2, 3 in order from top to bottom. For example, the specific coordinates of the detection point 2-2 are (77.5, -45, 0).

![Figure 3. Detection surfaces setting](image)

3. Light detection simulation parameter setting
Starting from upper cover to lower cover, select 27 cross sections in the cavity, with a distance of 10 mm between each two cross sections.

Divide each cross section with 12 radii, the angle between every 2 radii is 30°. The simulation sequence is shown in Figure 4: start from the y-axis, rotate in the direction of the negative semi-axis of x, that is, counterclockwise when viewed from the top. It’s clearly that 30° and 330° are symmetrical, 60° and 300° are symmetrical, 90° and 270° are symmetrical, 120° and 240° are symmetrical, and 150° and 210° are symmetrical. On each radius, a discharge power source is arranged every 20mm, and the distance between the discharge power source and the center is 0mm, 24mm, 44mm, 64mm, and 84mm, respectively.
Figure 4. Discharge source position changing

4. Analysis of simulation results
Considering the case where the xy coordinate of the discharge source is (0, 44) and the z-coordinate changes from -135 to 125, analyze the light spot pattern, luminous flux and change rule on detection surfaces 1-3.

Figure 5 is an irradiance analysis diagram for a spot-shaped power supply located at coordinates (0, 44, 95), detection surface 1, detection surface 2, and detection surface 3 are in that order from left to right. And the coordinate axis setting is the same, the color change can visually represent the change of luminous flux.

According to the light spot image, as the distance between the detection surface and the discharge source increases, the color gradually changes from red yellow to green blue, the outline gradually blurs, and the distribution is more uniform. Comparing the total luminous flux, it can be found that the values decrease sharply with distance, as shown in Table 1.

| Detection Surface  | Distance from discharge source (mm) | Total luminous flux (W) |
|--------------------|-------------------------------------|-------------------------|
| Detection Surface 1| 5                                   | 103.74                  |
| Detection Surface 2| 95                                  | 22.458                  |
| Detection Surface 3| 185                                 | 12.272                  |

It shows that as the distance increases, the influence of the direct light on the detection surface gradually decreases, the light signal received by the detection surface gradually weakens, and at the same time the effect of reflected light gradually strengthens, making the light spot uniform.
Similarly, we can get the irradiance analysis diagrams of spot-shaped power supplies with xy coordinates (0, 44) on other cross sections. Based on the data of 27 cross sections, the z-coordinate of the discharge source is taken as the abscissa, and the total luminous flux of the detection surface is taken as the ordinate. The results are shown in Figure 6.

Figure 6. Influence of z-coordinate of discharge source on the luminous flux

It shows that the curve of detection surface 1-3 reaches its peak when the abscissa, that is, the z-coordinate of the power supply is 95, 5, and -85, respectively. According to the simulation model, when the z-coordinates of the detection surface 1-3 are 90, 0, and -90, that is, when the power source is closest to the detection surface, the total luminous flux of the detection surface is the largest.

The three curves all show a trend of rising first and then declining, that is, with the increase of the distance between the discharge source and the detection surface, the total luminous flux gradually decreases. And with the same amount of change, the total luminous flux on the left side of the peak of the curve will be greater than on the right side. The reason should be that when the z-coordinate of the power source is smaller than the detection surface, the light emitted by the power source is mainly blocked by the cone electrode connecting pole, when the z-coordinate of the discharge source is greater than the detection surface, the emitted light is mainly blocked by the disk electrode. The shielding effect of the disk electrode is more obvious than that of the cone electrode connecting pole.

Considering the case where the xz coordinate of the discharge source is (0, 65) and the y-coordinate changes from 0 to 84, analyze the light spot pattern, luminous flux and change rule on detection surfaces 1-3.

Figure 7 is the irradiance analysis diagram for detection surface 1. The power supply coordinates are (0, 0, 65), (0, 24, 65), (0, 44, 65), (0, 64, 65) and (0, 84, 65) in that order from left to right. And the coordinate axis setting is the same, the color change can visually represent the change of luminous flux.

Figure 7. Irradiance analysis(surface 1)

According to the light spot image, as the distance between the detection surface and the center of the body increases, the proportion of the red part decreases rapidly, and the part below the center gradually turns yellow-green. Comparing the total luminous flux, it can be found that the values decrease sharply as the distance from the discharge source to the center increases, as shown in Table 2.
Similarly, we can get the irradiance analysis diagrams of spot-shaped power supplies with xz coordinates (0, 65) on detection surface 2 and 3. The y-coordinate of the discharge source is taken as the abscissa, and the total luminous flux of the detection surface is taken as the ordinate. The results are shown in Figure 8.

![Figure 8. Influence of y-coordinate of discharge source on the luminous flux](image)

It shows that for a discharge source with a certain z-coordinate, as the y-coordinate of the discharge source increases, the distance from the center increases, the total luminous flux on the detection surface gradually decreases. When the distance is less than 44mm, the total luminous flux curve does not change much and the value decreases slowly; when the distance is greater than 44mm, the total luminous flux curve changes greatly and there is a significant downward trend.

### Table 2. Luminous flux of surface 1

| Y coordinate of discharge source | Total luminous flux (W) |
|---------------------------------|-------------------------|
| 0                              | 83.968                  |
| 24                             | 82.42                   |
| 44                             | 79.982                  |
| 64                             | 74.169                  |
| 84                             | 62.41                   |

5. Conclusion
When the power source is closest to the detection surface, the total luminous flux on the detection surface is the largest. In the case of the same discharge parameters, the spot-shaped discharge power sources at the same xy coordinate and different z-coordinates, as the distance between the discharge source and the detection surface increases, the total luminous flux on the detection surface gradually decreases, and it generally shows a rising first and then decreasing trend.

And with the same z-coordinate change, the total luminous flux on the left side of the peak will be greater than on the right side. That is, when the z-coordinate of the power source is smaller than the detection surface, the light emitted by the power source is mainly blocked by the cone electrode connecting pole. When the z-coordinate of the discharge source is greater than the detection surface, the emitted light is mainly blocked by the disk electrode. The shielding effect of the disk electrode is more obvious than that of the cone electrode connecting pole.

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The research in this paper only draws preliminary conclusions for the spot-shaped discharge power supply. The discharge performance of other insulation defects needs further research. In addition, the integrated detection methods can be considered [11-12].

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