Effect of Atmospheric Conditions on Discharge Characteristics of Rod-plane Air Gap

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Effect of Atmospheric Conditions on Discharge Characteristics of Rod-plane Air Gap

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Abstract. The rod-rod air gap electric fields are perfectly symmetrical in all kinds of extremely inhomogeneous electric field while the maximum asymmetry exists in the rod-plane air gap electric field. Other types of uneven electric field air gap breakdown characteristics fit in between. The rod-plane air gap electric field is an important reference for the designing of insulation strength. In this paper, the impact tests of rod-plate air gap are carried out in the field environment of different altitudes. Discharge characteristic curves of switching and lightning impulse at different environmental factors were given. The increases of the 50% discharge voltage of the rod-plane air gap switching impulse and rod-plane air gap lightning impact are larger. The influence of altitude on rod-plane air gap lightning impact is tiny. Through the analysis of test results, the influence mechanism of environmental factors on the discharge characteristics is also discussed.

1. Introduction
As the level of transmission voltage increases, the dielectric strength of the air gap becomes a major factor in the design of the outer insulation geometry[1].

In engineering practice, most of the electric fields are inhomogeneous electric fields. The rod-rod air gap electric fields are perfectly symmetrical in all kinds of extremely inhomogeneous electric field while the maximum asymmetry exists in the rod-plane air gap electric field. Other types of uneven electric field air gap breakdown characteristics fit in between. For a variety of very uneven electric field air gap that is encountered in the actual project, electrical strength can be estimated by the breakdown characteristics of the two typical air gap, rod-rod air gap and rod-plane air gap, according to the symmetry of their electrodes[2–4].

The air gap’s withstand voltage value of external insulation of transmission project is closely related to the atmospheric conditions [5]. At present, the research on the discharge characteristics of long-air gap caused by environmental factors in domestic and foreign laboratories is mostly limited to small-sized low-pressure vessels, focusing only on humidity and pressure [6-9]. It not fully considers the actual temperature, humidity and strong radiation effects, and also ignores the factors such as scene of the electromagnetic environment in the real field. If condition allows, it would be a more effective way to carry out experiments in the high-altitude field environment.

In this paper, the impact discharge of rod-plane air gap is investigated in a place along the coast of China (altitude of 50m) and somewhere in the Qinghai-Tibet Plateau (altitude of 4300m). The effects of air gap distance, polarity effect, temperature and altitude and other factors on the impact discharge have been studied, and certain regular pattern about the Influence of different atmospheric
environment on Impact discharge characteristics of rod-plane air gap can be drawn. This study provides a reference for other research about electrode used in high altitude area.

2. Test Equipment and Test Methods

2.1. Rod-plane Electrode Arrangement
The rod-plane air gap electrode is vertically arranged. The upper end of the rod electrode is suspended by a composite insulator which is 12m long while the lower end of the insulator is connected with a power supply wire and a 15m long galvanized steel pipe. The plane electrode is a stainless steel plate with a thickness of 3mm and is provided with a 20m*20m square grounding iron plate.

2.2. Basic Parameters of the Impact Generator
The impulse voltage is generated and measured by the impulse voltage generator and its measurement and control system. The basic parameters are shown as table 1.

| Environment Conditions | Temperature (°C) | Average Temperature (°C) | Atmospheric Pressure (kPa) | Absolute Humidity (g/m³) | Average Absolute Humidity (g/m³) | Altitude (m) |
|------------------------|-----------------|--------------------------|---------------------------|-------------------------|-------------------------------|-------------|
| Low altitude and low temperature | -5~5 | -1 | 101 | 2~5 | 4.1 | 50 |
| Low altitude and high temperature | 15~25 | 21 | 101 | 4~11 | 6.0 | 50 |
| High altitude and high temperature | 15~25 | 18 | 60.5 | 3~7 | 5.3 | 4300 |
2.4. Test Methods and Test Results

In this paper, the impact test is conducted by method recommended GB/T 16927.1-1997 high voltage test technology Part I: General test requirements [10] and GB311.1-1997 high voltage power transmission equipment with external insulation matching [11].

In engineering practice, the breakdown voltage characteristic of the air gap is usually featured by the voltage at the 50% breakdown (U_{50}). The 50% impulse discharge voltage has the same changing rule as the nominal value and the per unit value. The impulse discharge voltage in this paper is expressed by the per unit value. The minimum value of the 50% impulse discharge voltage in each test is taken as the reference value, and the 50% impulse discharge voltage in the test is taken as the per unit value.

\[ U_{50e} = \frac{U_{50}}{U_{50B}} \]  

In the equation: \( U_{50} \) is the real value of the 50% impulse discharge voltage, kV; \( U_{50B} \) is the reference value of the 50% impulse discharge voltage, the minimum value in each test, kV.

The dispersion of the data of the test data can be showed by the coefficient of variation, while the greater the coefficient of variation, the greater the data dispersion gets. The coefficient of variation is calculated as follows:

\[ z = \frac{\sigma}{U_{50}} \times 100\% \]  

In the equation above: \( U_{50} \) is the 50% discharge voltage, kV; \( \sigma \) is the standard deviation.

3. Effect of Temperature on Discharge Characteristics of Rod-Plane Air Gap

The curve of lightning impulses and switching impulse (\( U_{50e} \)) of the rod-plane air gap at low temperatures (-5~5°C) and high temperatures (15~25°C) in a coastal area changes with gap distance \( d \), as is shown in Figure 1. The comparison of the coefficient of variation of the two experimental data is shown in Table 3. Besides temperature, other environmental conditions for the impact test are basically the same.

![Figure 1](image_url)

**Figure 1.** The relationship between switching impulse \( U_{50e} \) and the gap distance \( d \) as well as the relationship between lightning impact \( U_{50e} \) and the gap distance \( d \) in different temperature.
Table 3. Coefficient of Variation of Rod-plane Air Gap Impact U50

| Impact Type                   | Coefficient of Variation (z) |
|-------------------------------|------------------------------|
| Switching Impulse(low temperature) | 2.7%~4.8%                   |
| Switching Impulse(high temperature) | 3.1%~4.6%                   |
| Lightning Impact(low temperature) | 1.9%~3.0%                   |
| Lightning Impact(high temperature) | 2.4%~2.8%                   |

As can be drawn from Figure 1 and Table 3:

(1) The effect of temperature on the impact polarity of the rod-plane air gap is great: when the air gap distance is in the range of 1m~5m, the switching impulse at low temperature U50(−) increases by about 17%~8% comparing to it at high temperature U50(+). The larger the gap distance, the smaller the increase of U50(−). The switching impulse U50(+) at low temperature increased about 1%~3% compared with the U50(+) at high temperature. The greater the gap distance, the greater the difference between them. When the air gap distance falls in the range of 2.5m~7m, the lightning impact at low temperature U50(−) increases by about 6%~12% comparing to it at high temperature U50(+). When the air gap distance falls between 2.5m and 7m, the lightning impact at low temperature U50(+) increases by about 10%~12% comparing to it at high temperature U50(+).

(2) When the temperature rises, the saturation tendency of the switching impulse voltage of the rod-plane air gap increases and the effect of temperature on the saturation trend is small.

(3) The temperature effect on the distribution of rod-plane air gap impact discharge U50 is more complicated. Within the selected test temperature, the dispersibility is no different.

4. Influence of Altitude on Rod-Plane Air Gap Discharge Characteristics

The curve showing the relationship between lightning impulses and switching impulse (U50*) of the rod-plane air gap taken at a coastal area (50m) and a place in the Tibetan Plateau (4300 m) and gap distance d is shown in Figure 2. The comparison of the coefficient of variation of the two experimental data is shown in Table 4. Besides altitude, other environmental conditions for the impact test are basically the same.

Figure 2. The relationship between switching impulse U50* and the gap distance d as well as the relationship between lightning impact U50* and in different altitude
Temperature and altitude affect the impact discharge characteristics of long air gap discharges. As altitude increases, the collision ionization is more likely to occur because of the increasing of mean free path of free electrons in the air, which increases the collisional ionization. As the temperature increases, the average kinetic energy of the gas molecules increases, the probability of collisional ionization increases, and the initial electrons are more likely to appear. When the altitude increases, the air density decreases, while the mean free path of free electrons in the air increases. As a result, the collision ionization is more likely to occur because of the increasing of the kinetic energy accumulated during free electrons acceleration. Temperature and altitude affect the impact discharge characteristics by affecting the pilot discharge process in long gap discharges.

5. Conclusion and Analysis

When the other environmental conditions are close to each other, temperature and altitude are chosen as two parameters for studying the influence of single environmental factor on the air-gap discharge voltage. The influence mechanism of environmental factors on the discharge characteristics is also discussed. The main conclusions of this thesis are as following:

(1) As altitude increases, the $U_{50}$ of the rod-plane air gap decreases; the saturation trend of switching impulse $U_{50}$ drops. Altitude has following effect on the impact discharge characteristics of the rod-plane air gap: $U_{50}$ at an altitude of 4300 m is about 65%~85% of it at an altitude of 50 m for a positive-polarity switching impulse; for a negative-polarity switching impulse at an altitude of 4300 m $U_{50}$ is about 60%~70% of it at the sea level of 50m. $U_{50}$ at an altitude of 4300 m is about 60% of it at an altitude of 50 m for a positive-polarity lightning impact; for a negative-polarity lightning impact at an altitude of 4300 m $U_{50}$ is about 70% of it at an altitude of 50m.

(2) As the altitude increases, the polar effect of the rod-plane air gap decreases.

(3) According to the test data dispersion analysis, it is found that the dispersion of the impact discharge $U_{50}$ of the rod-plane air gap in the high altitude area is generally lower than that in the low altitude area.

### Table 4. Coefficient of Variation of Rod-plane Air Gap Impact $U_{50}$

| Impact Type           | Coefficient of Variation (%) |
|-----------------------|-----------------------------|
| Switching Impulse(50m) | 2.9%~4.9%                   |
| Switching Impulse(4300m) | 2.8%~4.8%             |
| Lightning Impact(50m)  | 2.4%~2.8%                   |
| Lightning Impact(4300m) | 2.6%~2.9%                 |

As can be drawn from Figure 2 and Table 4:

(1) As altitude increases, the $U_{50}$ of the rod-plane air gap decreases; the saturation trend of switching impulse $U_{50}$ drops. Altitude has following effect on the impact discharge characteristics of the rod-plane air gap: $U_{50}$ at an altitude of 4300 m is about 65%~85% of it at an altitude of 50 m for a positive-polarity switching impulse; for a negative-polarity switching impulse at an altitude of 4300 m $U_{50}$ is about 60%~70% of it at the sea level of 50 m. $U_{50}$ at an altitude of 4300 m is about 60% of it at an altitude of 50 m for a positive-polarity lightning impact; for a negative-polarity lightning impact at an altitude of 4300 m $U_{50}$ is about 70% of it at an altitude of 50 m.

(2) As the altitude increases, the polar effect of the rod-plane air gap decreases.

(3) According to the test data dispersion analysis, it is found that the dispersion of the impact discharge $U_{50}$ of the rod-plane air gap in the high altitude area is generally lower than that in the low altitude area.

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