Study on the Electric Field Distribution Characteristics of the DC Arrester in the Case of Pollution

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Abstract. The DC electric field has a strong adsorption effect on the polluted particles of the substation, so the surface of the DC surge arrester is more prone to fouling. The DC pole bus arrester of the UHV converter station will change the electric field on the external insulation surface and the electric field between the resistance valve and the insulation jacket due to its internal resistance sheet structure characteristics, so it will have a certain impact on the operation status of the arrester. In this paper, by constructing a simulation model of the pollution electric field on the surface of the UHV DC pole bus arrester, the distribution characteristics of the surface pollution in the DC field are studied, and the radial electric field characteristics of the umbrella skirt surface when the surge arrester is wetted and the local drying zone occurs are calculated. It will enhance the surface field strength and the internal radial field strength of the insulating jacket, but the value is small, and it will not cause surface corona and flashover and other discharge phenomena; but when the local dry zone appears on the surface, it will be on the outer insulating surface and the resistance valve A penetrating discharge with the insulating jacket will have a serious impact on the safe and stable operation of the arrester.

1. Introduction

UHV DC transmission technology is increasingly mature and developing, and a large number of converter stations have been put into operation. The DC pole bus arrester of the converter station (hereinafter referred to as "pole bus arrester") is the most important overvoltage protection device in the DC field of the converter station. The pole bus arrester is usually installed outside the DC field. It is affected by wind, sunshine, high temperature and severe cold and other severe weather factors all the year round, and gradually forms a dirty layer mainly composed of dust and salt [1-4]. And because the DC electric field has a strong adsorption effect on the polluted particles of the substation, the surface of the DC surge arrester is more prone to fouling. Therefore, it is necessary to conduct research and analysis on the distribution characteristics of the internal and external electric fields of the pole bus arrester in a strongly polluted environment. Literature [5-7] used artificially manufactured different pollution conditions to study the pollution resistance of AC and DC arresters under different voltage levels and different pollution conditions, but the test takes a long time and has a large error. It only monitors the leakage current and cannot control each. The electric field distribution inside and outside the arrester. Literature [8-10] carried out simulation analysis on the pollution accumulation characteristics of the DC line insulators and the electric field distribution characteristics under different pollution conditions through electric field simulation. The simulation results show that the position, voltage distribution, wind direction and wind speed of the DC insulator umbrella skirt All the factors will affect the pollution distribution characteristics of the surface, and when the moisture causes the leakage current to increase
and the local dry zone occurs when heated, it is very easy to cause flashover on the surface of the insulator. In addition, the different pollution distribution characteristics of the pole bus arrester will change the electric field distribution characteristics of the electric field on the outer insulation surface, which will affect the safe, stable and reliable operation of the arrester. The pollution distribution on the surface of the DC insulator is affected by various factors such as the position of the umbrella skirt, voltage distribution, wind speed and wind direction, and the pollution layer will be on the surface of the insulator after undergoing processes such as water absorption and moisture absorption, increased leakage current, and local drying bands due to heating and drying.

This paper studies the different distribution characteristics of the arrester pollution in the DC field, builds a simulation model of the pollution electric field on the surface of the UHV DC pole bus arrester, and carries out theoretical simulation calculations on the external insulation surface electric field and the electric field between the resistance valve and the insulation jacket.

2. Pollution simulation model of pole bus arrester

The ±800 kV UHV DC pole bus arrester is made up of five sections of arrester sections connected in series, each section has a height of 2852 mm, each section has three columns of resistance plates in parallel, and is divided into upper, middle and lower three resistance plate packaging units (the number of resistors in each column of the middle, middle and lower units are 14, 16, 14). The resistance sheet is pie-shaped, with a diameter of 106 mm and a thickness of 23 mm. Each piece is separated by an aluminum gasket with the same diameter and a height of 20 mm. Figure 1 shows the external overall and internal structure of the pole bus arrester of the converter station as shown in Figure 1. Under the DC operating voltage, under the normal DC operating voltage, the potential distribution of the internal resistance valve is relatively uniform, and the voltage distribution of each section is similar. And ignore the influence of the DC tube bus and other equipment. In order to simplify the simulation calculation process and ignore the influence of other equipment in the DC field, this paper uses a single lightning arrester section in the single-node pole bus arrester to establish a simulation model, which can be simplified simulation calculation process. At the same time, while simulating the application of a layer of thickness on the outer surface of the porcelain cover of the arrester, this paper builds a simulation model of the electric field under the surface area of the arrester by adding a layer of pollution with a thickness of 1 mm to the outer surface of the porcelain cover. The resistivity of the layer reflects the different pollution states as shown in Figure 2.

Figure 1. Structure diagram of polar bus arrester

Because the upper surface of the pole bus arrester jacket is washed by more intense rain, the self-cleaning ability is stronger than the lower surface, which causes the lower surface to be heavier than the upper surface. Its salt density and gray density are about 5-7 times of the upper surface [11, 12]. And because the DC voltage has a sedimentation effect on the dirty particles, more dirt particles will be adsorbed at the higher field strength on the surface of the insulating jacket. Figure 3 shows the simulation results of the average field strength of the surface of each umbrella skirt of the insulating jacket of the
arrester under the continuous operating voltage of 165kV. It can be seen that the field strength of the jacket surface is U-shaped from top to bottom, that is, the two ends are high and the middle is low, so the dirt density of the top and bottom umbrella skirts is higher than that of the middle umbrella skirt. Surface contaminants are mainly composed of soluble salts and insoluble substances such as silicon dioxide. The greater the salt density, the stronger the water absorption, and the easier the dirt layer is to be dampened and the lower the resistivity.

3. Simulation calculation of global wet pollution

According to the set parameters, the simulation simulates the electric field distribution characteristics of the single-pole pole bus arrester under the continuous application of DC 165 kV voltage. Figure 4 shows the characteristics of the electric field distribution of the jacket insulation. It can be seen that the locally high field strength appears at the tip of the outer skirt of the jacket, and the maximum values appear at the top and bottom, respectively, 0.373 kV/mm and 0.296 kV/mm. The reason is that the pollution density and range of the upper and lower surface areas of the umbrella skirt are different, and the resistivity of the pollution layer changes abruptly at the junction of the upper and lower surfaces. The field strength at the tip increases and the maximum appears.

As we all know, the initial field strength of the corona on the surface of the insulator is 0.45 kV/mm, and the simulation calculation results show that the maximum surface field strength and radial electric field do not exceed this value. Therefore, the overall contamination of the surface of the insulating jacket of the arrester does not cause Corona and flashover.
4. Simulation calculation of local drying zone

The wetting and fouling on the outer surface of the pole bus arrester will cause the leakage current to increase and the heat to increase, and a local drying zone is formed by drying the dirt. The power generated by the pollution layer on the unit area at a certain point on the umbrella skirt is:

$$P_w = \frac{U_f^2}{4 \rho_w \pi^2 f r^2}$$  \hspace{1cm} (1)

Where, $U_f$ is the distributed voltage, $P_w$ is the resistivity of the pollution layer, $f$ is the shape coefficient of the umbrella skirt, and $r$ is the distance from this point to the swivel shaft of the arrester jacket. The heat of vaporization required for water evaporation in the pollution layer per unit area is:

$$P_a = J \rho \alpha$$  \hspace{1cm} (2)

Where, $J$ is the wetting intensity, that is, the volume of water absorbed from the air per unit area of pollution layer per unit time; $r$ and $a$ are the density of water and the heat of vaporization. Then the conditions for the dry zone are:

$$P_a = P_w$$  \hspace{1cm} (3)

The simulation results show that the umbrella skirt drying belt first appeared on the top and bottom umbrella skirts of the arrester jacket. Figure 5 shows a schematic diagram of the local field strength on the surface of the umbrella skirt. It can be found that because the resistivity of the local drying zone is much greater than that of the rest of the area, and the voltage in the DC field is proportional to the resistivity, most of the voltage drop is borne by the drying zone, and the electric field is also abrupt here, resulting in a sudden change. The local field strength is too high. Therefore, the electric field distribution in the drying zone of the umbrella skirt is much higher than the other parts of the jacket. The maximum field strengths at the top and bottom drying zones are 8.089 kV/mm and 7.990 kV/mm, which are much larger than the initial corona field strength of 0.45 kV/mm and the air gap breakdown field strength of 3 kV/mm. Therefore, it will cause flashover breakdown along the surface of the insulating jacket of the lightning arrester, thereby generating discharge and accelerating the deterioration of the insulating material. In addition, from equation (1), it can also be seen that the higher the distributed voltage $U_f$, the lower the surface contamination resistivity, the higher the heating power $P_w$, the easier the moisture evaporates to form a dry zone, and the top and bottom surfaces of the insulating jacket The field is strong, the dirt accumulation density is large, and the resistivity of the dirt layer is low, so the drying zone will be formed first, which shows the correctness of the simulation results.

(a) Top dry zone  \hspace{1cm} (b) Bottom dry zone

Figure 5. Surface electric field of drying zone in different position

5. Conclusion

Based on the single section arrester as the research object, and combining the distribution characteristics of impurity in the DC field, established the UHV DC pole bus arrester filthy conditions, electric field
simulation model of the pole bus arrester in whole wet filth and local dry with an umbrella skirt surface electric field and resistance between the insulation coat and analysis of the radial electric field was calculated, and the following conclusions:

1. When the wetting body of the pole bus arrester is polluted, the surface field strength and internal radial field strength of the insulation jacket both increase due to the different fouling density at different positions on the surface of the insulation jacket, and the maximum value appears at the top and bottom, but the small value will not cause corona and flashover phenomenon.

2. The surface field at the top and bottom of the insulation coat is strong, the dirt density is high, and the dirt layer resistivity is low, so the dry zone will be formed first. The sudden increase of the surface field strength at the dry zone far exceeds the breakdown field strength of the air, which will lead to the flashover discharge along the surface of the insulation coat of the pole bus arrester and accelerate the deterioration of the insulation material.

3. At the same height as the local drying zone, a large radial electric field appeared. The maximum value of the radial field at the top and bottom was similar to each other, but in opposite directions. However, the values were both higher than the breakdown field of air. It can be seen that the surface of the pole bus arrester will flashover after fouling, wetting, heating and drying, as well as the penetrative discharge between the resistance sheet column and the insulation jacket. The deterioration of the resistance sheet and insulation materials caused by this phenomenon will be an important factor that endangers the safe and stable operation of the arrester.

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