Electric Field Analysis of 35kV Line Arrester Under Different Environmental Conditions

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Abstract. In actual operations, the surface insulation strength of metal oxide line arrester can be thus decreased due to inevitably dirt and icing, and the flashover voltage can be significantly reduced, which threatens the operation safety of the entire transmission line. Therefore, in this paper, the internal and external electric field and potential distribution of a 35kV line arrester under operating voltage are studied quantificationally. ANSYS and COMSOL finite-element software was used to calculate the field and potential distribution of the arresters under clean, polluted and icing condition. Based on the analysis of the electric field distribution, the main influence factors of the electric field and potential distribution as well as the equivalent calculation method under different environmental conditions of the arrester are obtained, which can give help to the design and application of line arresters under different environmental conditions.

1. Introduction

With the rapid development and extension of power system, the operating experience shows that most accidents occurred on transmission lines are caused by lightning[1]. At present, Metal-oxide Surge Arrester is widely used as a main limiting device for overvoltage in power systems, and its operational reliability is receiving more and more attention[2]-[3]. Compared with Metal-oxide Surge Arrester, Gapped Line Arrester has lower discharge residual voltage and lower resistance charge rate and therefore is commonly used in power transmission system[4]. Under the operating condition of power frequency, the line arrester should not respond to power frequency overvoltage, otherwise it may not be able to cut off the current and cause the breaking accident[5].

State Grid came up with a new closed type of 35KV Line Arrester with Internal Gap (IGLA). We mainly calculate and analyse the electric field distribution of the arrester under continuous operation voltage under clean, polluted and icing conditions. Software simulation method was used to simulate the actual installation of IGLA. Considering the influence of the shape of the shed and the electrode, the maximum field intensity of the electrode surface and the end of the resistor was calculated. Voltage class of this IGLA is shown in table 1.

Table 1. The voltage class and type of the IGLA.

Voltage class	Type	Maximum sustained line-to-ground voltage (kV)
35kV	Line Arrester with Internal Gap (IGLA)	23.24

2. Simulation calculated model

This type of closed 35kV IGLA is 0.638 meters high and the electrode gap distance is 0.2 meters. It is composed of upper and lower flanges, epoxy insulation cylinder, resistor, metal spacer, insulating bar and electrode. Relative permittivity of the materials are shown in table 2.

Table 2. Relative permittivity of the materials.

Type	Silicon rubber	Epoxy insulation cylinder	Air	Resistance plate	Insulating bar
Relative dielectric constant	4.0	5.0	1.0	600	5.0

Finite element model in the electro-static field of finite element calculation software COMSOL is used to calculate the equivalent capacitance. The equivalent capacitance of zinc oxide resistors is 42.06pF, while that of air gap is 1.37pF. Therefore, the body potential ratio should be approximately 3.16%. That is to say, the peak potential of the body should be about 1036V in the clean condition.

According to the structure of IGLA, its electrostatic field problem can be simplified into 2D axisymmetric electric field in engineering. Based on this theory, COMSOL Multiphysics model based on finite element algorithm was established.

The model is divided into three parts: calculating field, the arrester and far field. The electric field analysis type is the electric static field, and the potential of the boundary is 0. The boundary of the finite element method is 20~30 times the diameter and 4~5 times the height of the arrester.

3. Electric field analysis

3.1. Under clean condition of 35kV IGLA

The continuous operating voltage 35kV IGLA at full load is 35kV, which may reach 40.25kV if the power frequency overvoltage is increased. Therefore, the maximum voltage that each phase arrester may withstand will be the peak of phase-frequency overvoltage 32.864kV. The cloud diagram of potential and electric field distribution under continuous operating voltage is shown in figure 1 and figure 2.

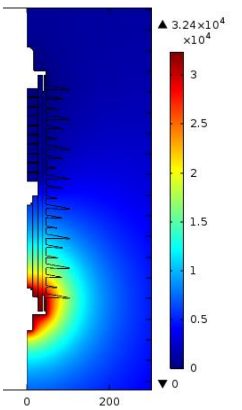

Figure 1. Potential field distribution under clean condition.

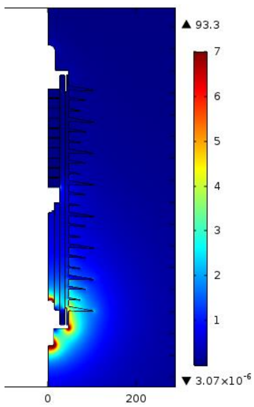

Figure 2. Electric field distribution under clean condition.

The result shows;The maximum field strength on the clean 35kV IGLA internal insulation material is 8.118kV/cm which is found in the insulating tube in contact with the low voltage electrode. The maximum field strength of air gap is 7.44 kV/cm.

3.2. 35kV IGLA with 2 kinds of conductive layer

When the Electrical conductivity of 1mm-thick layer is 10 μ S/mm, the results comparison is shown in table 3.

Table 3. Result comparison.

	Conductive layer thickness (*mm*)	Electrical conductivity of water film (μ S/mm)	Main body partial voltage ratio (%)	Air gap equivalent capacitance (pF)	Maximum electric field strength in silicon rubber （kV/cm）	Maximum electric field strength in electrode （kV/cm）
Clean	-	-	3.04	1.31	-	7.44
Polluted	1	10	3.19	1.39	16.37	26.34

From the table, the maximum electric field strength of the air gap will reach 170.5kV if the metal electrode is chamfered near the bending of the insulating tube, which is far beyond the safety range.

Other 4 electrical conductivities of water film were also calculated, which is 25 μ S/mm,40 μ S/mm, 80 μ S/mm and 1000 μ S/mm respectively. These 5 electrical conductivities is also simulated with 3mm-thick conductive layer. Results are shown below.

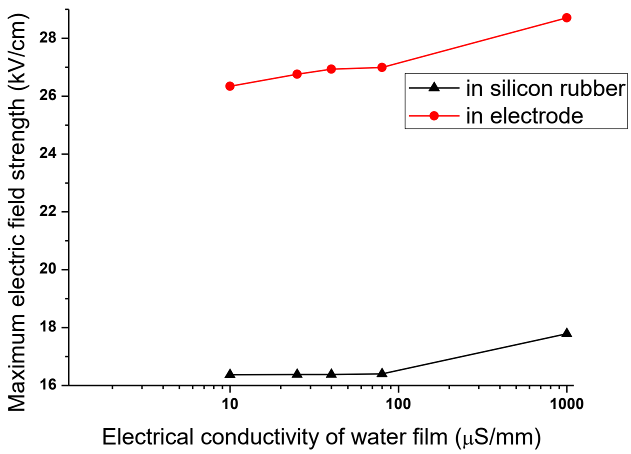

Figure 3. The electric field of 35kV IGLA under different environmental conditions.

For electrodes which contacts with the insulation material, any form of petty gap can cause electric field concentration, which is why the electrode surface that contacts with the insulating material frequently has black burning trace. The maximum electric field in the air gap is extremely high when the metal electrode is chamfered near the interface of the insulating tube. If such a situation occurs in practice, it is likely to cause the concentration point of the electric field, and then cause the internal flashover along the surface when the power frequency voltage is raised or even under continuous operating voltage. This can lead to misoperation of air gap and cause the breaking accident.

3.3. 35kV IGLA under icing condition.

3.3.1 Two sheds bridging. When two sheds are bridging by 15mm long icicle with 5mm thick ice on general surface, the condition is shown in figure 4.

Figure 4. Two sheds bridging indicated figure.

The cloud diagram of potential and electric field distribution under this condition is shown in figure 5 and figure 6. Under different environmental conditions, maximum field strength appears at different positions, which is shown in figure 7 below.

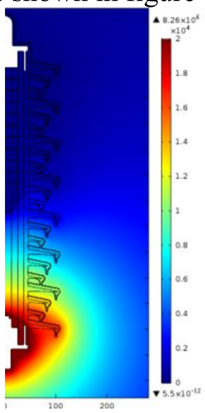

Figure 5. Potential field distribution under two-shed bridging condition.

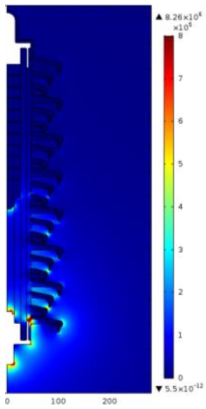

Figure 6. Electric field distribution under two-shed bridging condition.

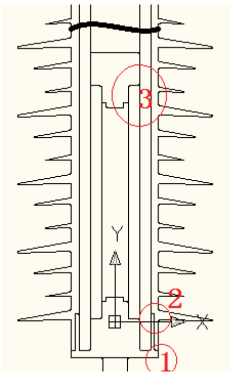

Figure 7. Maximum field strength position under different environmental conditions. 1-when the surface is clean; 2-when the surface is icing; 3-when the surface is polluted.
Note: The lower electrode is high voltage pole.

Conditions are taken into consideration when the water film conductivity is 10 μS/mm and 40 μS/mm. The result is shown in table 4 below.

Table 4. Maximum electric field strength in IGLA under two-shed bridging condition.

Ice layer electric conductivity	Silicon rubber	Electrode	The tip of an icicle
10μS/mm	19.655	15.40	7.28
40μS/mm	19.651	15.38	7.28

3.3.2. Three sheds bridging. When three sheds are bridging by 40mm long icicle with 5mm thick ice on general surface, the condition is shown in figure 8.

Figure 8. Three sheds bridging indicated figure.

The cloud diagram of potential and electric field distribution under this condition is shown in figure 5 and figure 9 and figure 10.

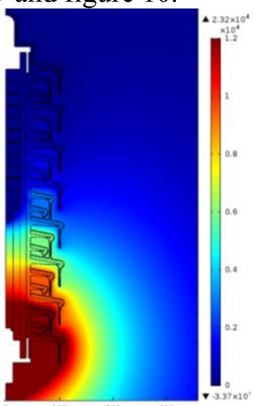

Figure 9. Potential field distribution under three-shed bridging condition.

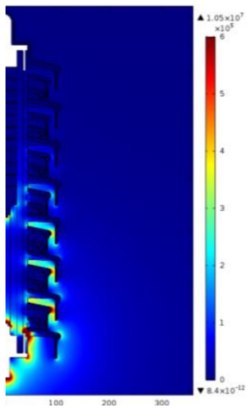

Figure 10. Electric field distribution under three-shed bridging condition.

Conditions are also taken into consideration when the water film conductivity is 10 μ S/mm and 40 μ S/mm. The result is shown in table 5 below.

Table 5. Maximum electric field strength in IGLA under three-shed bridging condition.

Ice layer electric conductivity	Silicon rubber	Electrode	The tip of an icicle
10μS/mm	27.913 kV/cm	16.77 kV/cm	23.71 kV/cm
40μS/mm	27.921 kV/cm	17.12 kV/cm	23.95 kV/cm

In any environmental condition, an IGLA can be regarded as an equivalent circuit in which the internal capacitance is in parallel with the external resistance. In the clean condition, the internal electric potential of the arrester is divided according to the equivalent capacitance of the resistor and air, and the external electric potential of the arrester is divided according to the equivalent creepage resistance of silicon rubber on the surface. In the polluted condition, the internal electric potential of the arrester is divided according to the equivalent capacitance of the resistor and air, but the external electric potential of the arrester is divided according to the equivalent resistance of the uniform conductive layer on the surface. Therefore, the IGLA has a very large potential difference in the height.

4. Conclusion

Comparing those three cloud diagrams of electric field distribution, we can easily see that the maximum point of electric field strength located at the interface of electrodes and the insulation material, and will extend as the environment growing severer. The reason why the maximum point located here is that the two different components cannot perfectly attach. The potential field distribution diagrams show the equivalent calculation method we use now is reasonable. To summarize, there are several conclusions after calculating and analysis:

(1) The reason why the electrode surface that contacts with the insulating material frequently has black burning trace is that, any form of small gap can cause electric field concentration, for electrodes which contacts with the insulation material. The maximum electric field in the air gap is extremely high which is likely to cause the internal flashover along the surface when the power frequency voltage is raise, leading to misoperation of air gap and causing the breaking accident. It will aggravate this problem when the weather condition turning severer.

(2) IGLA can be regarded as an equivalent circuit in which the internal capacitance is in parallel with the external resistance under any environmental condition. In the clean condition, the external electric potential of the arrester is distributed according to the equivalent creepage resistance of silicon rubber on the surface, while in the polluted condition it is distributed according to the equivalent resistance of the uniform conductive layer on the surface. As for the internal electric potential of the arrester, it is always distributed according to the equivalent capacitance of the resistor and air. Therefore, the IGLA has a very large potential difference in the height.

References

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