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Electrical field distribution of 35 KV Igla under polluted and ice-covered situation at power frequency

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Abstract: Lightning striking on power system may lead to severe accident and huge losses, which is the reason why line arresters are needed. During operation, the electrical field concentration in line arrester may lead to ablation and accelerated aging of insulation materials, and furthermore, cause mal-operation. A type of line arresters with internal series air gap (IGLA) is chosen by this study, which is distinguished from the previously used metallic oxide arrester, with better characteristic on anti-flashover when icing, but with worse characteristic on anti-flashover when polluted. This paper aims at studying the probable variation of power-frequency electric field of this new kind of IGLA under polluted and icing situation, and making further analysis on the reason why the electric field strength change like this.

1 Introduction

In recent years, the overhead-line failure caused by lightning still accounts for about 70% of the total faults in overhead lines in China [1]. Thus, metal oxide line arrester is popularly applied to prevent lightning. Nowadays, Surge arresters with series gap show even more advantages than those without gap, such as higher operational reliability, larger range of protection, and easier maintenance.

In the case of contamination and icing, the electrical field distribution of the gapped arrester may change considerably compared to when it is clean, resulting in partial material aging or even partial discharge [2, 3].

This article focuses on a new type of 35 kV closed line arrester with internal series air gap (hereinafter referred to as IGLA), trying to calculate and analyse the electric field distribution in the case of clean, polluted, and icing under power-frequency voltage. The finite element analysis method (FEM) was used in simulation of IGLA.

This essay takes the shape of sheds, electrodes, and icicles into consideration, imitates the real installing condition, and eventually calculates the maximum electrical field of some positions on IGLA.

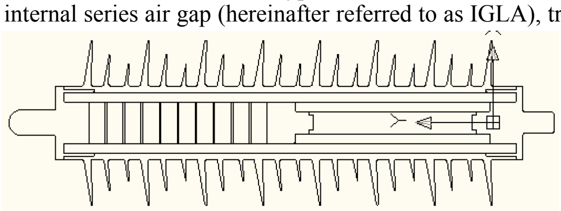

Fig. 1 *Structure of IGLA*

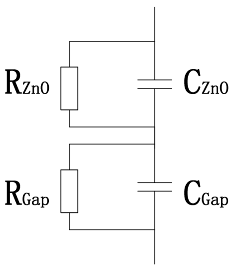

Fig. 2 *Equivalent circuit of IGLA*

Fig. 3 *Equivalent capacitance testing circuit*

2 Simulation model and calculation condition

IGLA consists of upper and lower flanges, epoxy insulation tube, silicone coverage, ZnO resistors, metal pads, insulated rods, and three electrodes and, with a 0.2-meters air gap and 0.638-meters height. The structure of IGLA is shown in Fig. 1.

2.1 Calculation model

Under power frequency operating phase voltage, both the ZnO resistors and the air gap possess the characteristics of capacitance together with the characteristics of resistance [4]. Therefore, both the ZnO resistors and the air gap could be seen as a parallel circuit of resistors and capacitors. The equivalent circuit of IGLA is shown in Fig. 2.

The capacitance of ZnO resistor could be directly measured by a Multi-Frequency Loss Tester DX8000, while the equivalent capacitance of air gap could be calculated by FEM analysis software. Finally, the capacitance of φ52/φ22 annular ZnO resistor turns out to be 512 pF, while the equivalent capacitance of air gap turns out to be 5 pF. Since the geometrical parameters of ZnO resistor are given, the relative permittivity can be easily calculated as 795 in Fig. 3

The resistance of ZnO resistor could also be directly measured by a Multi-Frequency Loss Tester DX8000. Aφ52/φ22 ZnO resistor is measured out to have 512 pF and 120.4 MΩ, which could be seen as parallel. Therefore, a φ52/φ22 ZnO resistor could be seen as a current divider, with capacitive current: resistive current = 19.35:1, which means the capacitive current is 95% of full current through the ZnO resistor. As for the air gap, the equivalent resistance of air gap is 7.8×10^{16} Ω, while the equivalent capacitance of air gap is 5 pF, which results in the fact that in the air gap capacitive current: resistive current ≈∞. That is to say, capacitive current dominate full current both in ZnO resistor and in the air gap. So a further conclusion could be drawn, that the voltage ratio of ZnO part and the gap part is determined mainly by

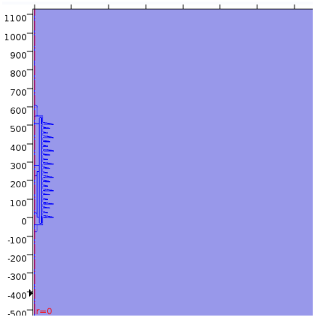

Fig. 4 *IGLA calculation model*

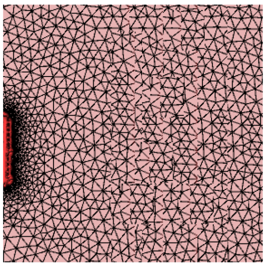

Fig. 5 *Meshed model of IGLA*

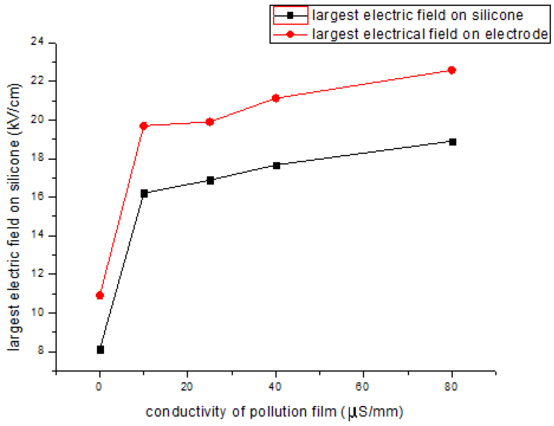

Fig. 6 *Largest electrical field on some parts of polluted IGLA*

the capacitive current, and hence the model is expected to be analysed by current field.

The establishment of COMSOL Multiphysics model based on finite element algorithm is shown in Fig. 4 – IGLA calculation model. The model is divided into three parts: arrester, calculation field, and far-field. As for the type of physics-field selection, the model is expected to be analysed by current field.

2.2 Mesh subdivision

Considering the geometrical characteristics of the model, Free Triangular Node is adopted to create an unstructured triangular mesh on the whole model. In an effort to ensure the accuracy of calculation, the size of mesh units is tightly related to the real dimensions. The subdivision of near-field air domain and the far-field air domain is also treated similarly. The mesh size of near-field air domain is smaller than the far-field air domain. The meshed model is shown in Fig. 5.

Model boundary conditions are set based on real conditions: The outermost air boundary together with the grounding electrode are set to 0 V, the high-voltage electrode is set to phase-voltage, and all the aluminium alloy are equi-potential body.

3 Results and analysis

3.1 Electric field distribution of polluted IGLA

Contaminated surfaces might give rise to dramatic effect on IGLA in operation condition. Here in Fig. 6, zero conductivity means a

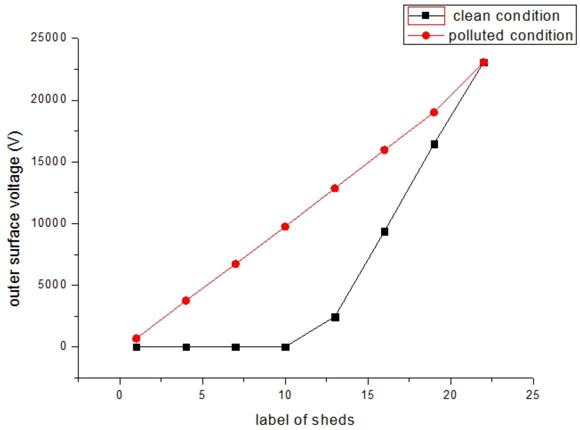

Fig. 7 *Voltage distribution of IGLA outer surface at the condition of clean and polluted*

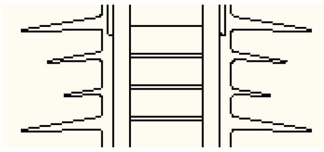

Fig. 8 *Arrangement of sheds*

clean outer surface, while non-zero conductivity means a wet and polluted outer surface.

The result can be summarised that, compared with a clean IGLA, the presence of pollution leads to a drastic increase in the electric field strength of IGLA, both on the silicone and on the electrode. In the fourth-level contamination (40 μS/mm), the electrical field strength of IGLA slightly increases compared to that in the first-level contamination (10 μS/mm).

The voltage distribution of IGLA outer surface at the condition of clean and polluted is shown in Fig. 7.

The figure shows that the external potential of a clean IGLA is mainly divided by the equivalent capacitance of ZnO resistor and the air gap, similar to the internal potential distribution [5]. By contrast, in the case of contamination, the external potential of IGLA is divided by the equivalent resistance of the uniform pollution film on outer surface. Therefore, compared with a clean IGLA, a polluted IGLA shows a larger potential difference on radial direction on a certain height, especially on height of the tenth shed accordingly in Fig. 7, resulting in a larger electrical field strength on radial direction. This fact explains why the presence of contamination causes a drastic increase in the electric field strength of IGLA.

3.2 Electrical field distribution of ice-covered IGLA

According to the arrangement of sheds shown in Fig. 8, sheds with three different sizes are placed periodically on the IGLA outer surface, which prevents the occurrence of icicle bridges effectively [6]. If all sheds were in the same size, then as long as the icicle reaches 2.4 cm, the icicles would connect the sheds from one end to the other, and probably lead to a mis-response to power-frequency operation voltage. A mis-response to operation voltage is a severe fault, resulting in huge current flowing through IGLA into the ground. Now only when the icicle length reaches 7.2 cm, the whole-connecting will happen.

Icicle bridges may occur between two sheds, or occur between three sheds. Thus, the largest electrical field strength on ice happens on distinguished positions in these two cases, shown in Figs. 9 and 10.

Results of Table 1 proves that, the assumption that the longer the icicles, the greater the electric field strength is not true. Actually, the maximum electric field strength on surface of ice is related to the specific shape of icicles and sheds.

There is a layer of water film when ice is melting, the thickness of which does make a difference on the maximum electric field strength on ice. The influence of water film is studied in Table 2.

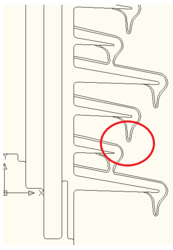

Fig. 9 *Icicle bridges occur between two sheds*

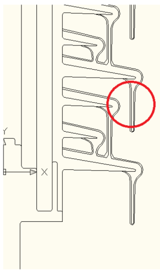

Fig. 10 *Icicle bridges occur between three sheds*

Table 1 Largest electric field strength on icicle with 1 mm water film

	Icicle bridges occur between two sheds	Icicle bridges occur between three sheds
electric field between icicles, kV/cm	9.34	7.68

Table 2 Largest electric field strength on icicle when icicle-bridges occur between two sheds

	Icicle bridges with 1 mm water film	Icicle bridges with 2 mm water film	Icicle bridges with 3 mm water film
electric field between icicles, kV/cm	9.34	12.48	15.38

The thicker the water film, the larger the electric field strength on ice, which could be easily seen in Table 2.

4 Conclusion

The concentration of electric field will lead to the ablation and aging of the material, which affects IGLA insulation to a certain extent. Therefore, the research on electric field distribution is of practical significance. Any form of small air gap between electrode and insulation material will cause the electric field to be extremely concentrated, which is the reason why the internal surface of the insulating material contacting to the electrode often shows traces of ablation. Both pollution and icing have negative impacts on electrical field distribution, so antifouling and anti-icing work cannot be ignored. In the analysis of contamination and icing conditions of the electric field strength, the IGLA can be seen as an equivalent circuit of internal capacitance in parallel with external resistor, which may help in understanding the electrical field changes.

5 Acknowledgments

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6 References

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