Potential and E-Field Calculation Along an Ice-Covered Composite Insulator with Finite Element Method

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***Abstract*—A 2-D FEM model for potential and electrical field calculation along an ice-covered composite insulator is presented. In order to find the influence of the ice on the potential and electrical field distribution, both various thickness of the ice and various lengths of the icicles are simulated. Moreover, the present study investigates the influence of the discrete water film and the dry band on the potential and electrical field distribution of the iced composite insulator. Then, this paper puts forwards the conclusion that the ice has great influence on the potential and electrical field distribution along the composite insulator. Furthermore, the maximum e-field strength along the composite insulator increases with the increase of the thickness of the ice and with the increase of the length of the icicles. Also, the water film and dry band are the important factors to influence the electrical field distribution along the ice-covered composite insulator.**

***Key words:* e-field, FEM, ice, composite insulator**

I. Nomenclature

FEM, finite element method.
Electrical field, e-field.

II. Introduction

In the West-to-East Power Transmission to be built in China, there will be a great amount of EHV transmission lines extended across the icing area. One of the serious problems with electrical power transmission by overhead lines, in such regions, is atmospheric ice accretion on insulators, which generally leads to a drastic decrease in their electrical performance, causing sometimes flashovers and consequent power outages [1], [2]. The performance of HV insulators under ice-free condition is quite different from those under ice-covered conditions. This is because, for an ice-covered insulator, the field distribution is capacitive-resistive depending upon the severity of the ice, while for a clean ice-free insulator the field is purely capacitive. Therefore, it is very important to know the changes in the field distribution induced by ice accretion around an insulator [3].

In order to find the process and the mechanism of the flashover on the ice-covered insulator, a great number of experiments have been carried out in the artificial climate chamber and the field station [4]-[12]. However, the flashover on the ice-covered insulator is a complex phenomenon which involves many factors such as the thickness of the ice, the length of the icicle, the water film melted from the ice surface, etc. Therefore, it is difficult to investigate that process and mechanism only by experiments. Due to the fact that the flashover voltage depends on the e-field distribution, the e-field distortion caused by the ice should be simulated. With this model, it can be found to which degree various icing factors influence the e-field distribution along the insulator. Furthermore, the developed model can be used in simulating the process of the flashover on the ice-covered insulator.

Composite insulator is widely used in China's power system because of its lighter weight, higher mechanical intensity, better anti-pollution performance and less maintenance required. Composite insulators are -in many instances preferred- above porcelain and glass insulators and have replaced them. But by now it has not been used in icing areas. In order to find the adaptability of the composite insulator in icing area, a lot of experiments have been carried out but it is still need further study [13].

In recent years, FEM is widely used in many fields such as structure analyses, chemical engineering, electromagnetic engineering, etc. Also, researchers on high voltage engineering have developed a lot of FEM models of clean insulator and polluted insulator. However, in our best knowledge, there are few FEM models regarding the icing condition of the insulator except the FEM model for the ice-covered post insulator set up by the CIGELE, Canada [3], [14].

With a FEM software, a 2-D FEM model for potential and e-field calculation along an ice-covered 110kV composite insulator is presented in this paper. Then in order to find the influence of the ice on the potential and e-field distribution, the FEM model with various thickness of the ice, various lengths of the icicles, various length of the dry band and the water films are studied.

The main objective of the present paper, in continuation with the previous Chongqing university studies, is to present a FEM model to find the influence of the ice on the e-field distribution along the composite insulator and to lay a foundation for the presentation of a FEM flashover model, which can predict the flashover voltage of the ice-covered composite insulator.

III. FEM Model Of Iced Composite Insulator

A. Model Setup

The e-field around the ice-covered composite insulator is not an accurate axisymmetric field. However, in order to simplify the model, this paper takes some measures to present the model as the 2-D axisymmetric one, that is, the high voltage electrode and the ground end of the insulator can be simplified to be axisymmetric, the presence of the ice and the icicles can be seemed to be uniform, the transmission line and the tower are omitted. Therefore, the potential and the e-field distribution can be calculated on a R-Z plane. The profile of that model is shown in Fig.1.

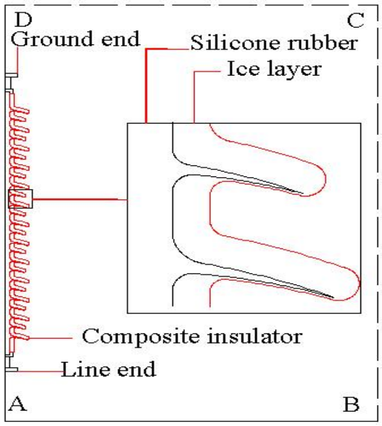

Fig.1. The FEM model of ice-covered composite insulator

When FEM is applied to solve the domain problem, the domain needs to be a bounded one. However, the domain of the ice-covered insulator is an unbounded one. Also, there are few kinds of commercial software that can solve the unbounded problem up to now. Usually, in order to solve that problem, an artificial boundary, far away from the interest domain where the electrical fields are effectively zero, is to be defined. In the present study, *BC* and *CD* are the artificial boundaries, as shown in Fig.1. *AB* is the ground, whose potential is supposed to be zero. *DA* is the axisymmetric boundary.

B. Simulation Parameters

The composite insulator used for modeling is a typical 110kV composite insulator with a dry arc distance h, 1150mm, a structure H, 1400 mm and a leakage distance L, 3300 mm, as shown in Fig.1. The voltage applied to the insulator model is the maximum phase voltage of 110kV system, 89.8kV.

This paper mainly models the composite insulator with the dry ice condition because it is difficult to simulate the wet ice condition. But in order to find the influence of the water film on the e-field distribution along the ice-covered insulator, the discrete water film and the dry band on the surface of the ice is simulated. In addition, aiming at finding the influence of both the thickness of the ice and the length of icicles on the potential and electrical filed distribution of the composite insulator, the ice-covered insulators with and without icicles are simulated separately in the present study. Furthermore, the thickness of the ice and the length of icicles are variable. Tab.1 shows the simulation parameters used in the present study. The conductivity of the air and the silicone rubber are neglected supposing all the leakage current flows in the ice in the case of dry ice condition, and in the water film in the case of wet ice condition.

TABLE1

SIMULATION PARAMETERS

	Silicone rubber	Ice	Water film	Air
Permittivity （ε_r）	6.0	70	81	1.02
Conductivity （μS/cm）	0	1	300	0
Thickness （mm）	—	Variable	1mm	—

IV. CALCULATION RESULTS AND DISCUSSION

The potential contours around the clean composite insulator are shown in Fig.2. From this figure, it can be found that the high voltage electrode sustains most of the applied voltage, and the maximum e-field strength along the 110kV composite insulator is at the point jointed the high voltage electrode and the silicone rubber, 7.5kV/cm. In this paper, this result can be compared with the calculation result of ice-covered insulator in order to observe the influence of the ice on the electrical distribution of the composite insulator. Also, the ice-covered insulators with and without icicles are simulated separately.

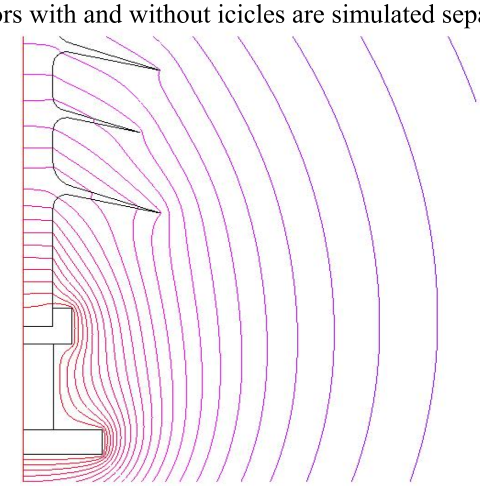

Fig.2. Potential contours around the clean composite insulator

A. The Influence of the ice layer on the E-field Distribution

In the present study, the influence of the thickness of the dry ice on the e-field distribution is investigated by simulating the FEM composite insulator with various average ice thickness, which range from 5mm to 15mm. The model profile is shown in Fig.1. The potential contours along the composite insulator with 5mm thickness ice layer are shown in Fig.3. Because almost all of the voltage is sustained near the high voltage electrode, the figure only shows the simulated domain near the high voltage electrode. Compared Fig.3 with Fig.2, the e-field along the composite insulator has significantly changed due to the presence of the ice layer. The ice near the high voltage electrode sustains most of the voltage. The maximum e-field strength along the ice surface is 13.19kV/cm, which is nearly two times of the maximum e-field strength along the surface of the clean insulator. Therefore, it can be concluded that the ice has great influence on the potential and electrical field distribution along the composite insulator. This is same of the simulation result of ice-covered post insulator [3], [14].

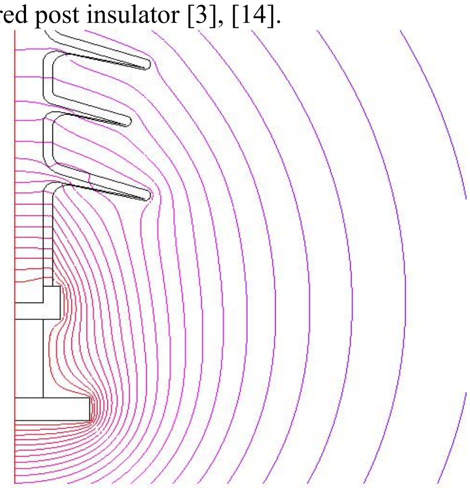

Fig.3. Potential contours around the composite insulator with 5mm ice layer

The relation between the three of the maximum e-field strength along the insulator and the thickness of the ice layer is shown in Fig.5. It can be seen that all of the three of the maximum e-field strength increase with the thickness of the ice. The maximum e-field strength, which is located at the joint point between the ice and the high voltage electrode, increase from 13.19kV/cm to 32.76kV/cm. Also, the other two of the maximum e-field strength also increase with the increase of the thickness of the ice layer. Moreover, because the maximum e-field strength exceeds 30kV/cm, the air breakdown e-field strength, the composite insulator with ice layer of 15mm is in a dangerous mode.

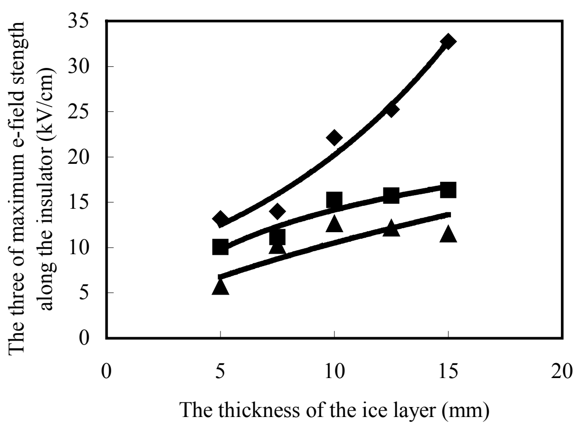

Fig.4 The relation between the thickness of the ice layer and the three of the maximum e-field strength along the insulator

B. The Influence of the Icicles on the E-field Distribution

This paper presents not only the study of the influence of the thickness of the ice on the e-field distribution along the ice-covered composite insulator, but also the study of the influence of the icicles, which is the important factor of e-field distortion around the ice-covered insulator, on the e-field distribution along the ice-covered composite insulator. The present study investigates the e-field distribution of the ice-covered composite insulator with the icicles of 10mm, 20mm, 30mm, 40mm, and 50mm length separately. The profile of the simulation model with 10mm icicles is shown in Fig.5.The thickness of the ice layer and the diameter of the icicles are kept at a steady value, 10mm. In order to simplify the simulation model, all of the icicles are kept at the same length.

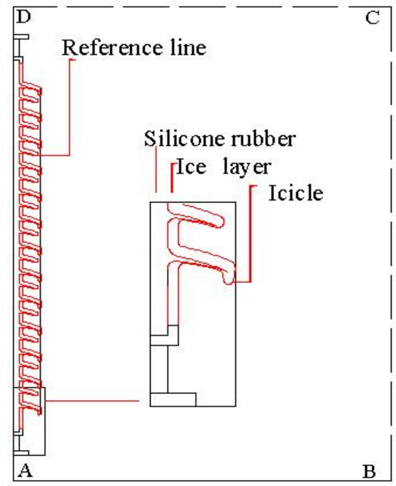

Fig.5. The profile of the FEM insulator model with icicles

Fig.6 shows potential contours around the composite insulator with 30mm icicles. It can be seen from Fig.6 that due to the influence of the icicles, the e-field along the composite insulator is distorted. Because the air gaps between the icicles and the sheds below start to sustain most of the applied voltage, the potential contours start to converge on these air gaps. The e-field strength near the high voltage electrode decrease, compared with the one near the high voltage electrode of ice-covered insulator without icicles.

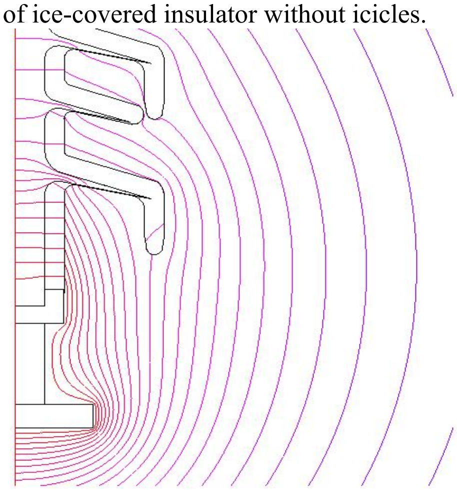

Fig.6 Potential contours around the composite insulator with 10mm icicles

Fig.7 shows the relation between the maximum e-field strength along the reference line shown in Fig.5 and the length of the icicles. It can be found from Fig.7 that the maximum e-field strength along the icicles increases with the increase of the length of the icicles. And the increase speed is also increasing with the increase of the length of the icicles. It can be concluded that the maximum e-field strength will exceed 30kV/cm when the length of the icicles are long enough. At that time, the local arc will appear among these air gaps, which will leads to the melting of the ice. Then the length of the icicles will decrease. Therefore, it can be concluded that the icicles are not easy to bridge the sheds of the composite insulator completely.

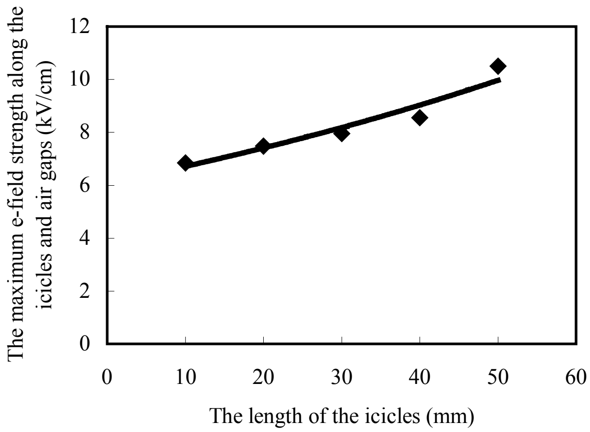

Fig.7 The relation between the length of the icicles and the maximum e-field strength along the icicles and the air gaps

Moreover, aiming at finding the influence of the diameter of the icicles on the e-field distribution along the composite insulator, this paper simulates the e-field distribution along the ice-covered composite insulator with various diameters of the icicles. The simulation model is same of that shown in Fig. 5. During the simulation, the thickness of the ice layer is kept at a certain value, 40mm, and the length of the icicles is kept at 50mm. Fig.7 shows the relation between the diameter of the icicles and the maximum e-field strength along the reference line shown in Fig.5. It can be seen from Fig.7 that the diameter of the icicles nearly has no influence on the maximum e-field along the icicles and the air gaps. This is because most of the voltage drop along the icicles and the air gaps is sustained by the air gaps. When the length of the air gaps kept at a certain value, the e-field along the air gaps will not change greatly.

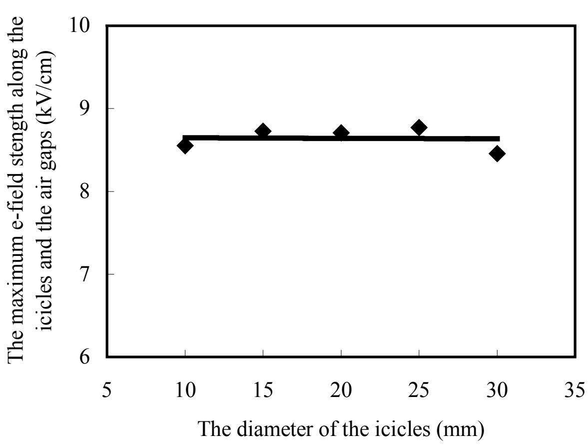

Fig.8 The relation between the diameter of the icicles and the maximum e-field strength along the icicles and air gaps

C. The Influence of water film on the E-field Distribution

In the case of energized ice-covered composite insulator, the leakage current melts the ice, which will lead to the appearance of the water film, as well as the consequent dry-band, on the surface of the ice layer. The local dry-band and the discrete water film are also the important factors, which cause insulator flashover. Therefore, this paper also simulates the influence of discrete water film and the local dry-band on the e-field distribution along the ice-covered composite insulator. Based on the discussion of section B and section C, it can be found that the location of the maximum e-field strength is near the high voltage electrode of the ice-covered composite insulator. Therefore, the present study simulates the discrete water film and the dry-band by adding two layers of water film near the high voltage electrode. The profile of the FEM model is shown in Fig.9. The dry-band between the water films, shown in Fig.9, is simulated with the length of 1mm, 2mm, 3mm, 4mm, and 5mm separately.

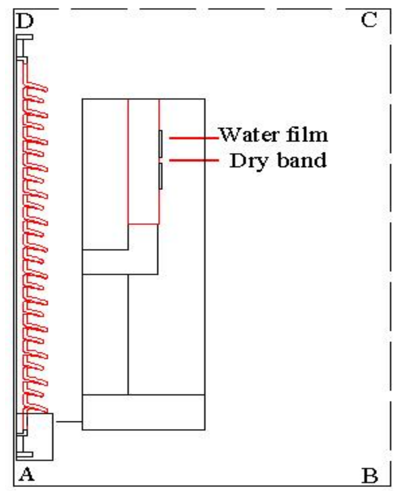

Fig.9. The profile of the FEM insulator model with discrete water films and dry-band

The e-field distribution along the water film, as well as the dry-band with the length 2mm, is shown in Fig.10. It can be found from Fig.10 that the dry band sustains most of the voltage drop along the water films and the dry band, which cause a peak value of e-field strength appears in the middle of the dry band.

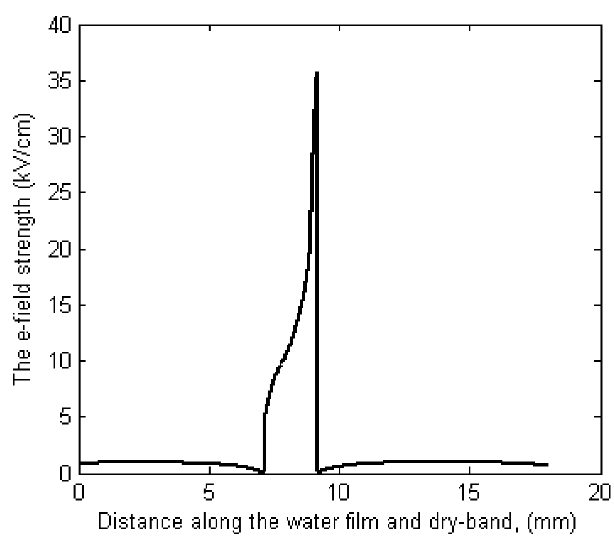

Fig.10 The e-field distribution along the water films and dry band (position zero is at the top point along the upper water film)

Fig.11 presents the relation between the maximum e-field strength along the dry band and the length of the dry band. It can be found from Fig.11 that the maximum e-field strength along the dry band increase with the decrease of the length of the dry band. When the e-field strength along the dry-band exceeds the breakdown e-field strength, the local arc will appear. The energy of the arc has two kinds of effect on the ice. On one hand, the energy can accelerate the ice below the dry-band melting, which will cause the water film appear on the surface of the dry-band. On the other hand, the energy can also desiccate the water films, which will cause another dry-band appearing. This is the reason why the process of the flashover of the ice-covered composite insulator always includes the process of arc burning and arc extinguish.

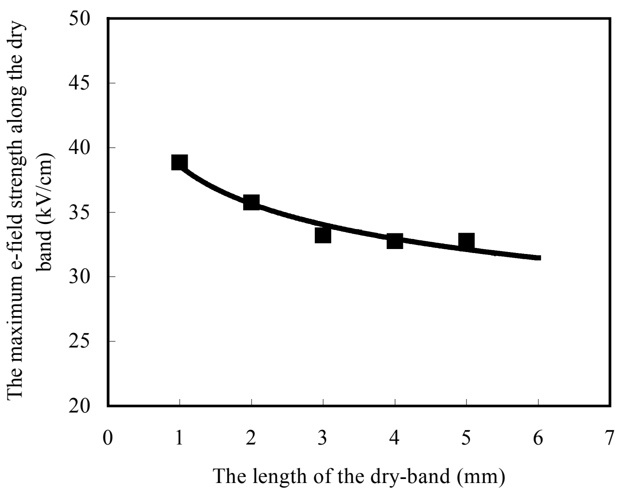

Fig.11 The relation between the length of the dry-band and the maximum e-field strength along the dry-band

V. CONCLUSION

(1) The presence of the ice layer and the icicles has significantly influenced the e-field distribution along the ice-covered composite insulator.

(2) The maximum e-field strength along the ice-covered insulator increases with the increase of the thickness of the ice layer.

(3) The maximum e-field strength along the icicles and the air gaps increases with the increase of the length of the icicles. Due to the high e-field strength along the air gaps, the icicles are not easy to bridge the sheds completely.

(4) The maximum e-field along the water films and dry-band increases with the decrease of the length of the dry-band.

(5) The presented FEM method can be further used to optimize the composite insulator for ice region and to lay a foundation for the presentation of a FEM flashover model of composite insulator.

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