Effect of binding wire on electric field distribution of overhead insulated conductor in distribution network

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Abstract. In recent years, the ablation damage of overhead insulated conductor on the top of insulators has posed a threat to the safe and stable operation of distribution network. In this paper, a three-dimensional model including insulator, binding wire and conductor is established in the finite element simulation. Then analyse the influence of the existence of binding wire and the diameter of binding wire on the electric field distribution of conductor. Providing a theoretical basis for the cause and prevention of the ablation damage of conductor insulation layer. The simulation results are as follows: When binding wire exists, electric field distortion will occur in the insulation layer and surface air around the conductor. The maximum electric field intensity of the surface air around conductor reaches 15.5kV/cm, which is about 690\% higher than that without a binding wire. The maximum electric field intensity of the insulation layer reaches 4.3kV/cm, which is 980\% higher than that without binding wire. In addition, as the diameter of the binding wire increases, the maximum electric field intensity in the insulating layer decreases and the maximum electric field intensity in the air on the surface around the conductor has small change.

1. Introduction
The use of insulated conductor in the distribution network greatly reduced the frequency of grounding short circuit, inter-phase short circuit, electrocution between human and animal, etc., and improved the power supply reliability of Chinese urban distribution network. In the overhead transmission lines of distribution network, the conductor is generally fixed on the top of porcelain insulator by means of binding wire. In recent years, during the actual operation of overhead insulated conductor in distribution network, it is found that the frequency of ablation damage in the insulator layer at the top of the porcelain insulator is gradually increasing. The damage of the insulation layer of the conductor will increase the risk of conductor breakage, and the damage is mostly near the binding line, where the insulation appears obvious electric ablation. Therefore, it is necessary to analyse the electric field distortion caused by the binding line to see whether there is a possibility of partial discharge.
In recent years, the insulation damage causes of aerial insulated wires have been paid much attention by the majority of scientific researchers. In the literature[1-4], from the perspective of the composition of insulation material structure, it is analyzed that the arc destroys the molecular structure and thus leads to the wire breakage. Literature[5-7] conducted field operation state tests and laboratory simulation tests on the actual insulated overhead conductors, which were caused by the leakage current provided at the cut break of the conductor and generated heat in some local areas with high current intensity. Electric field distortion is the root cause of partial discharge, and the influence of binding wires on electric field distortion has not been reported in literature.

In this paper, firstly, a simulation model is established to analyze the electric field distribution of the conductor with or without binding wires. And then, influence of binding wire diameter variation on electric field distribution of conductor is analyzed.

2. The three-dimensional finite element calculation model of binding wire, conductor and insulator is established

2.1. Geometric model of binding wire, conductor and insulator
A typical combination model of conductor, insulator and binding wire is shown in Fig.1, where the conductor insulation layer at the binding position is prone to breakage. The binding wire is aluminum strip with a diameter of 3mm. The insulator type is ps-15/300, the conductor type is JKLYJ-120, the radius of the conductor core is 0.62mm, and the thickness of the insulating layer of the conductor is 3.4mm. According to the available structural parameters and the actual measurement, the 3d model is built in the simulation software.

2.2. Calculation conditions of model
Under normal conditions, the operating voltage frequency of overhead conductors in the distribution network is 50Hz, and the length of conductors in the model is 40cm, which is far less than the wavelength of electromagnetic waves. Therefore, the influence of magnetic field on electric field can be ignored, and the physical field in the model is regarded as an electroquasi-static field. Its governing equation is as follows.

\[
\begin{cases}
E = -\nabla \varphi \\
\nabla \cdot (\varepsilon E) = 0
\end{cases}
\]

The off-line voltage of the overhead conductor in the 10kV distribution network in normal operation is 10kV, its unidirectional to ground voltage is 6kV, and its peak value is 8.2kV. The voltage of the conductor set under the model boundary conditions is 8.2kV, and the metal lower surface at the bottom of the insulator is zero potential.
3. Results and analysis

3.1. Effect of binding wire on electric field distribution of conductor
In order to more vividly illustrate the influence of the presence of conductor binding on the air area on the surface around the conductor and the electric field distribution in the insulation layer, the simulation software was used to establish two models, namely the existing binding wire model and without binding wire. In order to be able to direct observation of the air on the surface around the conductor and insulation of electric field distribution, the choice model of the electric field distribution in the xz plane as research object, the two models of xz surface electric field distribution are shown in Fig.2, by comparing the found that the existence of the binding wire will cause electric field distortion on the insulation layer and surface of conductor.

![Fig.2 The simulation results](image)

In order to further observe the electric field distribution on the xz surface around the conductor at the binding position, the amplification tool in the software is used to enlarge this area, as shown in Fig.3. It can be clearly observed that electric field distortion will occur in the insulation layer near the binding area and the air area between the conductor and the insulation layer through the following figures. Fig.3.

![Fig.3 After magnifying the electric field simulation distribution diagram of the conductor section at the binding position](image)

In order to quantitatively describe the influence of the binding wire on the electric field of the insulation layer and the air on the surface around the conductor, the electric field intensity of line c to d in the insulation layer is selected to measure the influence of the binding wire on the electric field distribution in the insulation layer, considering the area of distortion in the insulation layer directly below or directly above the binding wire. The area of air distortion on the surface around conductor is between the binding wire and the insulation layer in Fig.3. The electric field intensity data in curve ab is selected for measurement. The specific locations of cd and ab line are shown in Fig.4.
It can be seen from Fig.5 (a) that the electric field intensity in the insulation layer from c to d decreases slightly when there is no binding wire. In the presence of binding wires, the electric field intensity from c to d at beginning to and then increases sharply. The maximum electric field intensity without binding wire is 0.5kV/cm, and the maximum electric field intensity with binding wire is 4.3kV/cm, which is about 760% higher than that without binding wire. It can be seen from Fig.5 (b) that, when there is no binding wire, the electric field intensity in curves a to b is almost unchanged, and the maximum electric field intensity is about 1kV/cm. Having binding wire, electric field intensity decreases slightly at the beginning and then increases sharply from a to b. The maximum electric field intensity is about 15.5kV/cm, increases by about 1450% compared with that without binding wire.

By comparing the existence and non-existence of the binding wire, it is easy to know that the binding wire will cause distortion of the electric field on the surface around the conductor and in the insulation layer. Meanwhile, the influence of the diameter of the binding wire on the air area on the surface around the conductor and the electric field distribution in the insulation layer of the conductor is further analysed.

3.2. The influence of the diameter of the binding wire on the electric field of the conductor

In practice, due to regional differences, there is no uniform regulation on the diameter of the binding wire, and there may be different diameter of the binding wire. Based on this, It is necessary to analyse the influence of binding wire diameter on electric field distribution around conductor. Build only a circle in the simulation model for saving time.

Generally speaking, the radius distribution range of the binding wire is mainly between 2.4mm and 5mm. Based on this, the diameter of the parameters set in the simulation calculation software are 2.4mm, 2.8mm, 3.6mm, 4.0mm, 4.4mm, 4.8mm and 5.2mm. in Fig.6, there are the distribution of electric fields on xz surface of conductor.
The above four electric field distribution diagram can only show the electric field distortion on the surface around the conductor and the position of the insulation layer, but the effect of the diameter of the binding wire on the electric field distribution of the conductor cannot be effectively explained. Based on this, a straight line cd and a curve ab are established respectively in conductor to measure the electric field intensity. The positions of cd and ab are shown in Fig.4. The length of the curve ab increases with the increase of the radius of the binding wire.

It can be seen from Fig.7 (a) that when on the left of 0.24 point, electric field intensity increases as the diameter of binding wire increases. When on the right of 0.24 point, electric field intensity decreases.
as the diameter of binding wire increases. As the diameter of the binding wire increases, the maximum electric field intensity in the insulation layer decreases. When the diameter decreases from 5.2mm to 2.4mm, the maximum electric field intensity increases from about 3.15kV/cm to 3.9kV/cm, increasing by about 23.8%.

As can be seen from Fig.7 (b), The entire electric field intensity curve is very similar as the binding wire diameter changes. The maximum electric field intensity varies little.

To sum up, it can be speculated that with the increase of the conductor binding wire diameter, the maximum electric field intensity in the insulation layer decreases, while the maximum electric field intensity in the surface around the conductor only has small change.

4. Conclusion
Based on the results and discussions presented above, the conclusions are obtained as below:

(1) The existence of the binding wire will cause electric field distortion in the air and insulation layer on the conductor surface. When there is a binding wire, the maximum electric field intensity of air on the surface around the conductor reaches 15.5kV/cm, which is about 690% higher than that without a binding wire, and the maximum electric field intensity inside the insulation layer is 4.3kV/cm, which is 980% higher than that without a binding wire.

(2) As the diameter of the binding wire increases, the electric field intensity inside the insulating layer decreases gradually, while the electric field intensity of the surface around the conductor has small change.

(3) Through analysis, although there are binding wires and the surface electric field intensity of the conductor does not reach the air breakdown field strength of 30kV/cm, moisture pollution further distorts the electric field and partial discharge may occur.

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