Analysis of electric field distribution of cable insulation defects

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Abstract. A defective single-core power cable model of city network was established based on Ansoft/Maxwell in this paper. Then we simulated the electric-field of the operation of the cable during the normal and other defective circumstances such as with the air gap or water gap in the insulating layer, or the steel nail ligation in the power cable. By simulation, it is found that the existence of defects will cause the distortion of the surrounding electric field, and the distorted electric field will produce high frequency pulse current in the copper shielding layer, which provides a feasibility proof for diagnosing the cable insulation defects by measuring the leakage current.

1. Introduction
Power cable is an important part of the power system. With the continuous growth of China's electricity demand, the operation of power cable must be long-term, continuous, safe and stable [1]. Therefore, it is very important to detect the insulation state of the cable. The traditional routine preventive test can not effectively detect insulation defects and its destructiveness, besides, the power failure will cause serious economic losses. So in recent years, a large number of online insulation detection technologies have been studied at home and abroad [2-4]. At present, the following methods have been proposed, such as DC superposition, on-line dielectric loss tangent, low frequency superposition, grounding wire current method, etc. [5-7]. Although the DC method can reflect the aging degree of the cable, it has poor stability and low anti-interference ability. The low frequency rule will increase the harmonic components in the system and affect the power quality.

A defective single-core power cable model of city network was established based on Ansoft/Maxwell in this paper. Then we simulated the electric-field of the operation of the cable during the normal and other defective circumstance such as with the air gap or water gap in the insulating layer, or the steel nail ligation in the power cable. The leakage current on the copper shielding layer of the cable is simulated, which provides a feasibility proof for diagnosing the cable insulation defects by measuring the leakage current [8].

2. Model analysis of power cable
The electric field of 10kV power cable was simulated and analyzed based on Ansoft/Maxwell in this paper, and the finite element analysis method was selected. The excitation of voltage on cable core
will generate electric field around the conductor. Because the electric field changes slowly under low frequency voltage, it can be regarded as static electric field. Copper is selected as the core material, and then electrical conductivity and dielectric constant are set to the insulating medium of each layer, and the sectional structure diagram of single core cable is shown in Figure 1.

![Figure 1: The sectional structure diagram of single core cable](image)

The cable simulation model is established according to the actual conditions. The terminal parameters are: the copper core radius is 5.7mm, the insulation radius is 5.3mm, the semiconductor radius is 0.7mm, the copper shielding radius is 0.5mm, the steel tape armour thickness is 1mm, and the sheath radius is 8mm. The core of the power cable is a copper conductor with tight pressure, and the insulating layer is used for ultra clean cross-linked polyethylene. The dielectric constant is 2.25 and the conductivity is 0.

### 3. Simulation and analysis of the electric-field

In this section, we firstly simulated some usual operation conditions of the power cable including the normal state or with defects, and then analysed the electric-field under these circumstances.

#### 3.1. Under the normal operation conditions

Choosing the electrostatic field as solver, the inner copper core voltage is set to 14140v, and the shielding layer grounding voltage is 0V. The simulation result of the electric field is obtained as follows.

![Figure 2: Distribution of electric field in normal operation of 10kV cable](image)

From Figure 2, we can see that the electric field intensity that near the copper core is larger, the maximum electric field is about $3.6 \times 10^6$ V/m, the electric field outside the shielding layer is 0V/m, and the electric field on the shielding layer is almost 0V/m, which is because the shielding layer of semiconductor has the function of shielding electric field.

#### 3.2. With an air gap in the insulating layer

Keep excitation source the same and set a fan-shaped air defect with a cut angle of 0.174rad, a radius of 3mm and a length of 10mm. When the air gap is close to the copper core and destroys the semiconductor shielding layer, the simulation results are shown in Figure 3.
Figure 3: Distribution of electric field with air gap of 10kV cable

The result shows that the electric field near the air gap is distorted compared with the normal operation of the cable, and the changing of electric field near the shielding layer is the most obvious, which is about $2.6 \times 10^6$ V/m.

3.3. With a water gap in the insulating layer

The air gap is changed into the water gap in the model, and the other conditions are constant, then the simulation result is shown in Figure 4.

Figure 4: Distribution of electric field with water gap of 10kV cable

It can be seen that under the condition of water gap, the electric field of the cable is also distorted, the electric field intensity gradually decreases with the copper core of the cable, and it begins to increase at the semiconductor layer, reaching the maximum value at the copper shielding layer, which is about $7.5 \times 10^6$ V/m.

3.4. With a steel nail inserting into the cable

A fan-shaped steel nail with a depth of 6 mm, a thickness of 2 mm, and an amplitude of 0.087 rad was established. The simulation result is shown in Figure 5.

Figure 5: Distribution of electric field with a steel nail inserted of 10kV cable
The result shows that the electric field is distorted after the steel nail is inserted into the main insulation of the cable. The whole electric field is no longer decreasing outward, and the electric field intensity at the tip of the steel nail is the largest, which is about $1.2 \times 10^7$ V/m.

4. Simulation and analysis of the leakage current

In this section, we simulated and analysed the leakage current on the copper shielding layer of the power cable under these above-mentioned circumstances, the simulation results provide a feasibility proof for diagnosing the cable insulation defects by measuring the leakage current.

4.1. With an air gap in the insulating layer

Because there is no current in the static electric field, the solver is changed to a transient electric field, and then the voltage excitation in the cable core is set to the corresponding power frequency sine AC value. The stopping time is set to two cycles which is 40ms, and the maximum time difference is 1ms. The simulation results at a certain time are as follows.

![Figure 6: Distribution of the leakage current with air gap of 10kV cable](image)

We can see from Figure 6, the value of current distribution in the air gap has great differences with other position of cable, and reaches the maximum in the copper shielding layer, indicating that the existence of air gap would cause the surrounding electric field distortion, thus the copper shielding layer consequently induce the high-frequency leakage current.

4.2. With a water gap in the insulating layer

In the transient electric field, the results of the current simulation at a certain time are selected as shown in Figure 7. Because of the conductivity of the selected water medium, the distribution of the current in the water gap is larger than that in the air gap, and the maximum value is reached on the copper shield.

![Figure 7: Distribution of the leakage current with water gap of 10kV cable](image)

4.3. With a steel nail inserting into the cable

In the transient electric field, the results of the current simulation of the cable which has steel nail inserted is likewise shown in Figure 8. Because the electrical conductivity of the steel nail is large, the
current value at the steel nail is significantly higher than that in the other locations of the cable, and the current value reaches the maximum when the steel nail contacts with the copper medium.

![Image](image.png)

Figure 8: Distribution of the leakage current with a steel nail inserted of 10kV cable

5. Conclusions

According to the above simulation results, it can be seen that the electric field inside the cable will be distorted compared with the normal operation state, and the insulation between conductors will easily breakdown. For a long time, it will cause high-frequency discharge and produce high-frequency leakage current on the copper shielding layer. As the high frequency current component flows to the earthing end of the copper shield, the leakage current can be measured at the outlet of the cable joint and thus the diagnosis of the cable fault can be realized. The simulation results provide a feasible proof and theoretical basis for the diagnosis of cable insulation defects by measuring the leakage current.

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