Influence of pollution on potential and electric field distribution of porcelain insulator in 110kV transmission line

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Abstract. The spatial potential and electric field distribution of clean insulator and insulator with different degrees of pollution in 110kV transmission lines are analyzed with Comsol Multiphysics software. The results show that: The curve connected by the voltage borne by the single piece insulator in the clean insulator string is saddle-shaped. The voltage borne by the high-voltage end and the low-voltage end is large, while the voltage borne by the middle part of the insulator string is small. With the increase of pollution degree, the overall trend of potential distribution remains unchanged, but the higher the pollution degree is, the greater the maximum voltage on the high-voltage side of the insulator will be, and the smaller the minimum voltage on the low-voltage side will be. With the increase of pollution degree, the general trend of electric field distribution around insulator string remains unchanged, but the maximum value of electric field increases.

1. Introduction
Insulator is an integral part of overhead transmission and distribution lines, which has the function of electrical insulation and mechanical connection. Therefore, the normal operation of insulators plays an important role in the safe operation of power grids. Literature [1-2] summarized that polluted insulator in normal operation may flashover under adverse weather conditions, resulting in pollution flashover accidents. This kind of accident ranks the second in the total accidents of power network, next only to lightning accident, but its loss is 10 times of lightning accident. Literature [3] studied the influence of uneven pollution distribution on the electric field distribution of a single insulator, and the results showed that the influence of uneven pollution on the upper surface and the lower surface on the electric field distribution was greater than that on the circumferential uneven pollution. Literature [4] studied the distribution of electric field around the fzsw-10/4 type post composite insulator under different salt densities. It is concluded that the distribution characteristics of electric field along the surface of composite insulator umbrella skirt are almost the same under the condition of different salt densities, and only the maximum electric field intensity between umbrella skirt is changed. In literature [5], ANSYS was used to simulate the electric field and current density of glass insulator and porcelain insulator under different salt densities distribution. The results show that the uneven distribution of pollution is beneficial to reduce the surface leakage current of insulator string and increase the flashover voltage of insulator.

In this paper, the simulation model of porcelain insulator in 110kV transmission line is built by Comsol Multiphysics. By setting parameters to simulate the pollution degree on the surface of
porcelain insulator, the spatial potential and electric field distribution around the surface of insulator are studied when the surface is clean and uniformly polluted under different salt densities.

2. Establishment of simulation model

Because insulator has axisymmetric structure, two-dimensional axisymmetric structure can be selected in the simulation model of Comsol Multiphysics. Draw half of the two-dimensional axisymmetric figure of XP10-160 in CAD and import it into Comsol Multiphysics for simulation. See table 1 for the basic technical parameters of XP10-160. In fact, the medium is not ideal. On the one hand, conductors have a finite conductivity; on the other hand, the medium is lossy. Therefore, the relation between complex dielectric constant and dielectric constant can be expressed as:

\[ \varepsilon' = \varepsilon - j \frac{\sigma}{\omega} \]  

The \( \varepsilon' \) is the complex dielectric constant, \( \varepsilon \) is dielectric constant, \( \sigma \) is conductivity, \( \omega \) is the angular frequency. For a polluted insulator system, there is \( \omega \varepsilon \approx \sigma \). In this case, the complex dielectric constant is used instead of the dielectric constant. At this time, the electric potential and electric field around the simulated dirty insulator string are similar to the measured results [6].

Table 1. basic technical parameters of XP10-160.

| Type                          | XP10-160          |
|-------------------------------|-------------------|
| Nominal diameter disc-D (mm)  | 280               |
| Structure height-H (mm)       | 170               |
| The above-mentioned area (cm²)| 1047              |
| The below-mentioned area (cm²)| 1434              |
| Total area (cm²)              | 2481              |

The main body of XP10-160 is composed of steel foot, iron cap, cement and porcelain. The definition of material properties related to simulation is shown in table 2. The relative dielectric constant of pure water is set at 81. Although the polluted water film has good conductivity and can be considered as a conductor with certain conductivity, it is still a dielectric. Even if the salt density in the water film changes (that is, the conductivity changes greatly), the ability of the polarizing charge of the water film does not change much, so the relative dielectric constant of the dirty water film is still 81. The thickness of the polluted water film was set as 1mm [7]. In accordance with IEC 60507, the corresponding relationship between partial salt density and conductivity is shown in table 3.

Table 2. related material properties.

| Materials            | Relative dielectric constant | Conductivity(S/m)   |
|----------------------|------------------------------|---------------------|
| Porcelain            | 6                            | \( 2 \times 10^{-15} \) |
| Cement               | 8                            | \( 2 \times 10^{-16} \) |
| Filthy water film    | 81                           | \( 0.3 \sim 2.4 \)   |
| Air                  | 1                            | \( 1 \times 10^{-12} \) |

Comsol Multiphysics uses finite element method to calculate the distribution of potential and electric field in a bounded closed domain. Since the problem of potential and electric field on the surface of insulator is an open domain problem, the commonly used method is to set the required truncation boundary artificially. At this point, it can be considered that the electromagnetic field attenuates to zero at the truncation boundary. According to the simulation results in literature [8], when the thickness of the air layer around the insulator is \( d > 2.5D \) (\( D \) is the nominal disk diameter of the insulator), the surface potential of the insulator can reach the maximum, and the electromagnetic field at the truncated boundary can be neglected. The thickness of the air layer taken in this paper is 3.5D. When the boundary condition is added into Comsol Multiphysics, the voltage of 63.5kV is
applied to the steel foot of the lowest insulator and the iron cap of the highest insulator is set as the ground. Free triangle mesh are selected for mesh subdivision.

Table 3: the corresponding relation between salt density and conductivity.

| Equivalent salt density (mg/cm²) | Conductivity (S/m) |
|---------------------------------|-------------------|
| 0.025                           | 0.3               |
| 0.05                             | 0.6               |
| 0.1                              | 1.2               |
| 0.2                              | 2.4               |

3. Simulation results and analysis

3.1. Potential and electric field around Clean insulator

The three-dimensional potential distribution around the clean insulator string is shown in figure 1. The voltage drop of each piece of insulator is obtained by taking the potential of each piece of insulator steel foot and combining with the zero potential of the top insulator iron cap, as shown in figure 2.

The whole insulator string can be divided into three parts: the two pieces of insulators near the bottom of the insulator string bear a higher voltage, and the voltage change rate is relatively large; the middle of the insulator string bear a lower voltage, and the voltage change rate is relatively small. The insulator at the top of the string also undergoes a higher voltage than the one at the bottom. Figure 2 shows that the voltage borne by a single insulator is connected in a saddle-shaped curve, and the simulation results are consistent with the theoretical calculation results, verifying that the simulation model is correct.

The three-dimensional spatial electric field distribution of the clean insulator string is shown in figure 3. In figure 4, the electric field on the insulator surface is extracted based on the arc length of the insulator surface. It can be concluded from figure 3 and figure 4 that: (1) the electric field distribution of the whole string of insulator is not uniform, the electric field intensity value near the high-voltage end and the grounding end is large, and the electric field intensity value in the middle of the insulator is small. (2) for a piece of insulator, since the steel foot and the iron cap are conductors, and the metal shell makes its interior not affected by the external electric field, the field strength in the steel foot and the iron cap is zero. However, the field intensity at the junction of the steel foot and the porcelain part and the porcelain part and the iron cap changed greatly.
3.2. The electric potential and electric field around the insulator string with different degrees of pollution

Figure 5 is the salt of polluted insulator surface layer density is $0.025 \text{mg/cm}^2$, $0.05 \text{mg/cm}^2$, $0.1 \text{mg/cm}^2$, $0.2 \text{mg/cm}^2$, of the insulator around potential part of the simulation results.

As can be seen from figure 5, although the level of insulator pollution (salt density) is increasing, the trend of the potential distribution around the insulator string is almost unchanged. Since the

(a) $\rho_{\text{ESDD}} = 0.025 \text{mg/cm}^2$

(b) $\rho_{\text{ESDD}} = 0.025 \text{mg/cm}^2$

(c) $\rho_{\text{ESDD}} = 0.025 \text{mg/cm}^2$

(d) $\rho_{\text{ESDD}} = 0.025 \text{mg/cm}^2$

Figure 5. potential distribution around the insulator.
electric field line is always perpendicular to the equipotential line and the direction of the electric field line points to the direction where the electric potential decreases, the increase of insulator surface contamination also has little influence on the distribution characteristics of the electric field along the umbrella skirt. However, in order to further study the influence of pollution degree on the spatial potential value of insulators, potential extraction was carried out from bottom to top at the maximum outer diameter of the distance insulator 0.01m and in the same direction as the insulator axis, as shown in figure 6. As can be seen from figure 6, with the increase of pollution degree, the maximum value of the potential near the high-voltage end of the insulator increases and the minimum value of the potential near the low-voltage end decreases.

Figure 6. insulator potential extraction line.

In order to further study the influence of the degree of filth of the insulator surface electric field, draw the corresponding to $0.025 - 0.2 \text{mg/cm}^2$ under the four kinds of salt densities of the maximum field strength, as shown in figure 7. It can be seen that with the increase of the salt density in the insulator surface pollution layer, the maximum field intensity on the insulator surface also increases. According to the experimental results in literature [9], the flashover voltage of insulators can be reduced with the increase of pollution degree. The simulation results agree with the measured results.

Figure 7. maximum field strength under different salt densities
4. Conclusions

(1) the curve connected by the voltage borne by the single insulator in the clean insulator string is saddle-shaped, and the electric field has a large value at the high voltage end and the low voltage end, while the value in the middle of the insulator is small.

(2) with the increase of pollution degree, the overall trend of potential distribution remains unchanged, but the higher the pollution degree is, the greater the maximum voltage on the high-voltage side of the insulator will be, and the smaller the minimum voltage on the low-voltage side will be.

(3) with the increase of pollution degree, the overall trend of electric field distribution around the insulator string will not change, but the maximum electric field intensity will increase.

References

[1] Zhang zhijin, jiang xingliang, sun caixin . Research review on flashover mechanism of dirty insulators [J]. Power System Technology, 2008,32 (16) : 27-32
[2] Zhang zhijin, jiang xingliang, sun caixin . Research status and prospect of flashover characteristics of dirty insulators [J]. Power System Technology, 2006,30 (2) : 35-40
[3] Gao bo, zhang yating, wang qingliang, et al. Influence of pollution non-uniformity on insulator electric field [J]. Electromagnetic arrester, 2008, (3) : 13-16,21
[4] Li jing, xu pengjuan, Yang guang, et al. Effect of salt density on electric field and temperature field of composite insulator [J]. Journal of electrical engineering, 2008,13 (7) : 23-30
[5] Wang sheng-hui, liu peng, xie tang-wen, et al. Study on the surface pollution distribution characteristics of natural fouling insulators [J]. Electrical measurement and instrumentation, 2017,54 (8) : 21-27
[6] Asenjo S E, Morales O N. Low Frequency Complex Fields in Polluted Insulators[J].Electrical Insulation IEEE Transactionson, 1982, EI-17 (3) :262-268
[7] Gong yuqing. Finite element analysis of the electric field under the pollution of 500KV outdoor insulator [J]. China new technology and new products,2009 (19) : 17-17
[8] Yang qing. Surface electric field characteristics and discharge model of ice-coated insulator [D]. Chongqing university, 2006
[9] Zhang zhi-jin, liu xiao-huan, jiang xing-liang, et al. Influence of unevenness of contamination on ac flashover characteristics of xp-160 insulator strings [J]. High voltage technology, 2013,39 (2) : 280-286