Simulation and Analysis of Electric Field for the Disconnector Switch Incomplete Opening Position Based on 220kV GIS

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Abstract: It has accounted for a large proportion of GIS equipment defects, which cause the disconnector switches to incomplete open-close position. Once opening operation is not in place, it will arouse continuous arcing between contacts to reduce insulation strength. Otherwise, the intense heat give rise to burn the contact, which has a severe effect on the safe operation of power grid. This paper analyzes some typical defection cases about the opening operation incomplete for disconnector switches of GIS. The COMSOL Multiphysics is applied to verify the influence on electric field distribution. The results show that moving contact out shield is 20 mm, the electric field distribution of the moving contact surface is uneven, and the maximum electric field value can reach 9.74 kV/mm.

1. Introduction
Gas Insulated Metal-enclosed Switchgear (GIS) is an equipment which mainly includes circuit breaker, disconnector, voltage and current transformer, lightning arrester and other components, enclosing in a grounding metal shell, and filling with SF6 gas for insulation and arc extinguishing medium under certain pressure. As an important operating component of substation, GIS has been widely applied in power system because of high operation reliability, small amount of maintenance and low rate of occurrence of failures. However, once GIS gets out of order[1-2], it will cause long power outages and heavy workload to maintain, dismantle, reassemble, adjust and repair. Therefore, it has become an important issue to improve the operation stability of GIS devices, such as keeping these facilities in good condition for more efficient, decreasing trouble rating, making comprehensive analysis, finding out reasons and proposing solutions for GIS equipment. In this paper, an accident of unplanned outage is caused by the defect of disconnector switch that is incomplete divided in the GIS device at a substation in Guangxi power grid. The simulation of electric field is carried out by COMSOL Multiphysics, and the distribution of electric field is calculated when the disconnector switch opening operation is not in open position.

2. Typical case study
A single-phase-to-ground short circuit fault occurred for a disconnector switch disconnected incompletely when inverted operation at an electricity substation of Guangxi power grid. The circuit breaker cannot trip when inverted operation, leading to all the circuit breakers in operation within the same station were all tripped, and causing the substation lost voltage. Fault recording showed that B phase broke down and the fault distance was 0 km.
And then, the SF6 gas components in the enclosures of isolating switch phase B was tested. The test results showed that the SO2 component in SF6 gas was up to 286 μL/L, Much more than the upper limit 3μL/L[3]. Remove cover from the above defective air chamber for further examination, It is found that there were obvious ablative marks in the moving contactor of the disconnector switch B phase, and lots of black burn marks on the basin insulator connected by a static contact, and a very serious erosion mark on the wall of the gas chamber around the middle of the moving contact. What is more, the disconnector switch disconnected not in place, which caused the moving contact to extend out of the shield is about 20mm. (The reference standard for less than 7.5mm), as shown in figure 1.

Figure 1. B phase moving contact of disconnector is extend out of the shield

According to the shape of the moving contact surface, the moving contact had high voltage during operation, besides, the gas chamber wall was ground potential, which resulted in a similar rod-plate non-uniform electric field was formed between the moving contact and the cylinder wall with ground potential. Due to its large radius and smooth surface, the grading shield can obviously improve the field intensity distribution between energized part and inner cylinder wall, therefore, it was designed on the outer end of the contact to be protected. In normal operating conditions, the movable contact of the disconnector switch should be fully drew back into the grading shield after the switch opening operation. However, the moving contact of the faulty disconnector switch divided incompletely, and didn’t retract the shield entirely, distorting the original uniform electric field between Conductive part and inner cylinder wall, resulting in extremely uneven electric field, discharging the inner shell of GIS, which leaded to Single phase grounding trip accident[4-5].

Since the moving and static contacts of GIS disconnector is sealed in the metal cylinder, it is very difficult for site operation persons to judge whether the moving contact has been disconnected in place or not, and so are the defects. Therefore, the X-ray imager has been used to determine whether the device is abnormal. Figure 2 is a picture of the defected switch contact taken by X-ray imager. From the figure, it can be seen that the movable contact is extended outside the shield. Once the GIS disconnector switch is not in place, great potential safety hazard will exist to the safe operation of the equipment. The following pictures are simulated by simulation software to analyze the distribution of the electric field when the GIS disconnector switch separated not in place.

Figure 2. The X-ray diagram of disconnector switch with incompletely divided moving contact

3. Simulation and analysis of electric field
3.1 The principle of electric field simulation

The boundary conditions should be satisfied when the electric field is calculated for an isolated switch gas chamber.

On the surface of the inner conductor and the outer wall of the cylinder, the electric potential is:

$$\phi|_L = U \quad (1)$$

Where $U$ is a known potential, and the $L$ is the surface boundary of the inner conductor and the outer shell. On the interface between SF6 gas and basin shape insulator and so on, it should be satisfied:

$$\frac{\epsilon_1 \frac{\partial \phi_1}{\partial n}}{\epsilon_2 \frac{\partial \phi_2}{\partial n}} = \frac{\epsilon_1}{\epsilon_2} \quad (2)$$

$$\frac{\partial \phi_1}{\partial n} = \frac{\partial \phi_2}{\partial n} \quad (3)$$

Where $\epsilon_1$ and $\epsilon_2$ are the relative dielectric constant of the SF6 gas and the basin insulator, the $n$ is the outer normal vector of the interface. The surface of the suspended conductor in the air chamber is:

$$\phi = \phi_x \quad (4)$$

$$\int \epsilon_1 \frac{\partial \phi}{\partial n} dS = Q \quad (5)$$

Where and $Q$ are the surface potential and the surface charge of the suspended conductor.

3.2 Building simulation modeling

COMSOL Multiphysics is used to analyze the electric field of disconnector for GIS. Since GIS disconnector switch is a structure that three phases are not in the same shell, and each of the phases has an axis-symmetric structure, so the 2 dimension axis-symmetric AC/DC module is adopted in the simulation modeling. Figure 3 shows the geometric structure of the GIS disconnector switch, which mainly consists of three parts, the contact, the shield, and the gas chamber (SF6 gas).

![Figure 3. Structure chart of disconnector switch structure](image)

Material properties are shown in Table 1.

| Material  | Permittivity | Conductivity |
|-----------|--------------|--------------|
| Moving    | 1            | 5.9e7        |
| Shield    | 1            | 4.2e7        |
| SF6 gas   | 1.002        | 1.0e-10      |

3.3 Boundary setting and mesh generation

The Auto-CAD software is used to establish the isolating switch geometry model, and import into the COMSOL software. The geometry model is choose to force into entities from the drawing menu bar in the COMSOL software, and then separate objects. After these operations, the boundary conditions and solution domains for the imported model can be setting.
The different boundaries have different boundary conditions by boundary setting. The disconnector switch moving contact is exerted effective value of AC voltage 127kV, and gas chamber cylinder is setting to the ground, and all the rest of the internal boundary are setting for continuous, while the rest of the exterior boundary setting for electrical insulation. As shown in Figure 4, in order to improve the computational accuracy, grid dissection is performed at the moving and static contact and shielding cover.

Figure 4. Grid dissection of disconnector switch

3.4 Analysis of simulation results[6-8]
The comparison analysis of the simulation results are shown in figure 5 to figure 9.

Figure 5 shows cloud chart of the electric potential distribution of the disconnecting switch. Figure 5(a) and figure 5(b) indicate the potential distribution nephogram for the moving contact of isolating switch completely retracts into the shield and extends the shield 20mm. It is found that the potential distribution by comparison, figure 5 (a) is more regular than figure 5(b), and the higher potential of Figure 5(b) is closer to the static shield, which means reducing the fracture distance of the isolating switch and shortening the insulation distance between the fractures.

Figure 5. Cloud picture of electric potential distribution of disconnector switch

Figure 6(a) and Figure 6(b) are the electric-field distribution nephogram for the moving contact of isolating switch completely retracts the shield and extends the shield 20mm. It is also found that the electric field distribution by comparison, figure 6(a) is more regular than figure 6(b), and the electric field in figure 6(b) is distorted at the top of the moving contact out of the shield. In addition, the local electric field value reaches 9.74kV/mm, while the maximum electric field value is only 5.1kV/mm after the moving contact is completely retracted to the shield.
Figure 6. Cloud chart of electric field distribution in disconnector switch

The equipotential line distribution diagram of the disconnector switch is shown in figure 7. It can be found that the moving contact has completely retracted back to the shield in figure 7(a). And the potential gradient at the top of the moving contact becomes very small, indicating that the electric field distribution is relatively uniform. But in figure 7(b), the moving contact extends out of the shield 20mm, the potential gradient at the top of the moving contact is very large, indicating that the potential distribution is not uniform and exists a large electric field value.

Figure 7. The equipotential line distribution diagram of the disconnector switch

Figure 8 is the distribution diagram of equal electric field of disconnector switch, obviously, figure 8 (a) is more uniform than figure 8 (b). Figure 8(a) shows that the electric field on the moving contact
surface is lower than that on the shield surface. The maximum value of the electric field on the moving contact surface is only half of the maximum value on the surface of the shield, indicating that the shielding cover plays the role to protect the moving contact. Figure 8(b) shows that the electric field on the moving contact surface is much higher than that on the shield surface. The maximum value of the electric field on the moving contact surface is two times as much as the electric field on the surface of the shield. When the moving contact is completely retracted, the electric field at the top of the moving contact is completely homogenized by the shielding case. When the isolating switch is in the process of tripping, the moving contact is just divided to completely retracting the movement of the shield. The electric field at the top of the moving contact is shading from weak to strong, and then from strong to weak. In addition to make the electric field uniform to protect the movable contact, the shield also helps to extinguish the arc.

Figure 8. Equal electric field distribution Nephogram of isolating switch

Figure 9 is the three-dimensional distribution of the electric field in the disconnector switch. The maximum electric field in Figure 9(a) is mainly distributed on the shield surface, while the maximum electric field of Figure 9(b) is mainly distributed on the top of the moving contact. If the moving contact can not completely retract back to the shield, the electric field of moving contact surface can not be homogenized by the shielding cover, which will cause a large electric field on the moving contact surface, especially a tip defect at the top of the contact, the surface electric field will be larger. If the moving contact can completely retract into the shield, the shield can make the surface electric field of the moving contact become well-distributed, and if a tip defect exists at the top of the moving contact, the electric field can also be effectively reduced.
4. Conclusion

This paper mainly introduces the non-planned outage accidents caused by the incomplete separation disconnector switch of the 220kV GIS. The moving contact of the fault isolating switch extends out of the shielding cover beyond 20mm, distorting the electric field on the contact surface, causing the moving contact discharge to the cylinder wall, which is the direct reason of relative short circuit.

The simulation analysis is carried out on the defects of the disconnector switch, which is disconnected by the electric field simulation software.

The simulation results show that the maximum of local field strength at the top of the moving contact is 5.1kV/mm when the moving contact of the disconnector switch completely retracted into shielding case. While the movable contact of the disconnector switch exceeds the shield 20mm, the electric field at the top of the moving contact reaches 9.74kV/mm. Therefore, the incomplete disconnection of disconnector switch will lead to uneven distribution of electric field on the surface of moving contacts, resulting in partial discharge and power blackouts and seriously affecting the safe operation of power grids.

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