Study on the mechanism and influencing factors of SF6 decomposition products

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Abstract. The decomposition products of GIS basin insulators have characteristic components under four conditions: different defects of GIS basin insulators, cracks and surface discharge of insulation parts inside GIS, abnormal heating of silicon packing basin insulators under steady state current, and particulate discharge of insulation parts. The characteristic components of decomposition products of SULFUR hexafluoride are introduced. Different mechanisms of decomposition products in partial discharge defects and abnormal heating defects were analyzed. The effects of partial discharge defects, abnormal heating defects and adsorbents on the decomposition products were studied.

1. Introduction

Gas insulated switchgear commonly used in China’s power grid includes GIS, SF6 circuit breaker, SF6 mixed gas switch, etc. [1]. Defect diagnosis is one of the key measures to ensure the safe operation of power grid. A large number of accident statistics and analysis show that the defect of internal insulation parts is an important source of equipment failure. The defects of solid insulation parts in operating switch equipment are dynamic development and even cause insulation deterioration. Different gaseous or solid decomposition products are produced in different stages of defect development.

SF6 device of two kinds of common faults mainly discharge and overheating, under normal circumstances, SF6 equipment does not produce toxic gases, but after the SF6 equipment malfunction, will produce a series of chemical reactions, the chemical reaction happens, will produce lots of toxic gases, insulating material under high temperature pyrolysis will go wrong, these products contain a lot of sulfur, so the equipment used in the link, should be to test the content of sulfur dioxide, total amount of sulfur dioxide concentration were analyzed. The equipment does not produce a large amount of sulfur dioxide in the immediate process of failure, but the concentration of sulfur dioxide increases as the amount of decomposition products increases. It is of great significance and reference value to the operation and management of switch equipment to analyze the generation of the mechanism and influencing factors of decomposition products under partial discharge and abnormal heat.
2. Characteristic components of decomposition products for internal insulation defects of switching equipment

In SF6 switching equipment, the decomposition product characteristic components of internal insulation defects can be generated in the process of surface insulation surface, mechanical cracks, abnormal heat, surface discharge of insulation rod, particle discharge of insulation parts, crack discharge and abnormal heat.

(1) SF6 gas decomposition products produced by different defects of GIS basin insulators have the following characteristics: 1) Insulation surface and spike discharge defects both produce a large amount of CO2 and SOF2, and a small amount of CO and SO2F2; 2) SO2F2 and COS were generated along the surface defects of insulation, and the large content of CF4 and the small content of CS2 were generated by using the iron electrode; 3) The insulation defect produces many components and high content. The gas composition and content produced by the iron electrode is more than that of the copper electrode.

(2) the GIS cracks and creeping discharge, when the internal insulation breakdown products feature components: aluminum packing basin reacts with SF6 gas insulation of critical temperature should be no higher than 140 °C, SO2, H2S, CO2 levels remained stable in the early stage of the test, tests to a certain critical point, can present obvious growth trend, should be to determine the response of the characterization of material, moreover C2F6 may at the early stage of the working condition of the response, SO2F2 can also be one of the characterization of the material in this reaction.

Silica filler basin insulator (3) in the process of steady state power flow abnormal heat decomposition product characteristics: silica filler basin react with SF6 gas insulation of critical temperature is not higher than 221 °C, SO2, CO, CO2 content remained stable in the early stage of the test, tests to a certain critical point, can present obvious growth trend, is to determine the reaction of substance, moreover C2F6 in the early days of the working condition of the response to it, CS2 may also be one of the characterization of the material in this reaction.

(4) Characteristic components of particle discharge decomposition products of insulating parts: CO2, SOF2 and SO2F2 are the main characteristic decomposition products under free particle discharge defects, and SO2 does not change significantly with the discharge process. Under the same conditions, the two kinds of free particle discharge decomposition products have the same type. Content changes show an increasing trend, but the output value of the same product under almost the same conditions has a great difference. This is due to the large dispersion of free particle discharge. CO2 may come from the reaction of the active C atoms released by the stainless steel electrode and epoxy resin insulation material with the impurity O or H2O in the process of local discharge. The concentration of the two sulfur products SOF2 is higher than THAT of SO2F2, in which SOF2 may be mainly generated by the hydrolysis of SF4, while the formation of SO2F2 may be mainly generated by the reaction of SF2 and O2. In addition to the generation of CO2, SOF2 and SO2F2, a new product CF4 was also detected in the decomposition products under fixed particle discharge. And CF4 is generated when the fixed particles are put down at a high discharge voltage. Therefore, it is inferred that C comes from the cracking of epoxy insulating materials.

3. Generation mechanism of decomposition products under insulation defects

3.1. Partial discharge defects

American scholar R. J. VanBrunt and others put forward the "regional reaction model", as shown in Figure 2, which is helpful to explain the partial discharge decomposition mechanism of SF6. The discharge area of SF6 gas chamber mainly includes glow area, ion drift area and main gas chamber [2]. It can be seen that the physical and chemical processes in the three regions are significantly different. The decomposition of SF6 into SFX mainly occurs in the glow region. Primary decomposition product SFX(X=1,2... 5) SF4 and SF2 are unstable, while SF2 and SF4 have the symmetrical structure and are relatively stable, so SF4 and SF2 are the main decomposition products of SF6 in the glow discharge area. The decomposition of SF6 to produce SF4 requires lower energy than the production of SF2 [2],
so the content of SF₄ is higher. Although SF₃ is unstable, SF₆ is most easily decomposed into SF₅, which reacts to generate SOF₄ and further generates SO₂F₂. Therefore, SF₅ generation will also affect the generation of SO₂F₂. In the main gas chamber, SF₄, SF₂ and SOF₄ react with impurities such as water and oxygen to produce more stable decomposition components SO₂F₂ and SOF₂, which are the main stable products generated by SF₆ decomposition under partial discharge [2].

Figure 1 Gas decomposition mechanism SF₆ partial discharge

If there are carbon-containing materials around the discharge area (such as stainless steel metal electrodes, solid insulation materials, etc.), F atoms and O atoms in the gas chamber will react with C atoms released by carbon-containing materials to produce products such as CF₄ and CO₂. At high temperatures, C atoms also react with CO₂ to form CO[3].

3.2. Abnormal fever defect
Although SF₆ gas is thermally stable under normal conditions, and SF₆ is inactive below 500°C, and the electrical equipment operates at room temperature, some temperature of high points will also occur in the GIS equipment. The occurrence of these points is due to the increase of energy demand or poor electrical contact. If the temperature of these points is close to or even over 200°C in the limited area, some metals begin to react with SF₆ gas and generate fluoride and sulfide of the metals. Due to the thermal effect, SF₆ molecules begin to separate and near and materials (such as metal or organic insulating materials) or impurities (water, oxygen) reaction of SF₆ gas decomposition components, in addition to fluoride and sulfide in the metal shell surface formation, also found that the decomposition of gas components of SO₂, moisture with significant effect for the formation of SO₂. Below 300°C, SF₆ gas mainly reacts with carbon or sulfur oxides, which erode the surfaces of metals and organic materials. At 350°C, the concentration of SF₄ did not increase significantly, but the content of SO₂ did. At 400°C, H₂S content began to increase, and the temperature was a little higher to 450°C. HF and SOF₂ were mainly generated. The critical temperature of SF₆ gas decomposition is 600°C, above which SF₆ gas decomposition generates SF₄ and SF₂[4].

In most cases, H₂S can be generated from any sulfur element where it comes into contact with organic materials, especially at high temperatures. The typical first catalytic stage is 315 °C to 330 °C, and the high temperature in the first stage also contributes to the hydrolysis of H₂S and CS₂ [4].

Compared with gold property overheating, the types and quantities of gas decomposition products produced by solid insulation overheating are obviously different from those produced by metal overheating. The main gas decomposition products are SOF₂, SO₂, CO and CO₂ under the overheating of the gold property. Of CO and CO₂ in the C source for release of the active C, high temperature stainless steel surface and under the solid insulation parts is overheating, SF₆ gas is not only involved in thermal decomposition reaction of solid insulation parts and high temperature cracking and
decomposition has led to the diversity of the decomposition product, in addition to containing a large number of SOF₂, SO₂, CO and CO₂, and new product gas generated, such as CH₄, H₂S, COS and CF₄.

4. Influencing factors of decomposition products caused by insulation defects

4.1. Partial discharge defects
The influence of SF₆ pressure on decomposition products under fixed metal particle discharge is shown in Figure 2. It can be seen that under high voltage, the initial partial discharge voltage of SF₆ gas increases, which is not conducive to the generation of corona and limits the discharge energy. The output of decomposition products decreases accordingly. The output of CO₂, CF₄, SOF₂+SO₂ and SO₃F₂ all decreases with the increase of air pressure.

![Figure 2: Effect of pressure on decomposition products under partial discharge](image)

(SF₆+150 µL/L H₂O, U=27 kV)

4.2. Abnormal fever defect
Under the condition of absolute pressure 0.5mpa, superheat failure temperature 300℃ and no adsorbent, SF₆ decomposition experiment under superheat of solid insulation parts was carried out, and the initial water content in the gas chamber was kept consistent. By comparing the yields of decomposition products at 0.3MPa and 0.5MPa, it can be found that the yields of decomposition products H₂, CO, CH₄, CO₂, H₂S, COS and SOF₂+SO₂ all increase with the increase of air pressure. In addition, when SF₆ pressure increases, the new product CS₂ is also detected.

4.3. The influence of adsorbent on the detection of decomposition products
In order to absorb moisture, impurities and decomposition products in SF₆ gas, adsorbents are generally installed in SF₆ electrical equipment, which will affect the determination of equipment faults [5]. In an ideal state, the adsorption rate of THE adsorbent KDHF-03 to THE SO₂ and SOF₂ gases in the decomposition products of SF₆ will gradually decrease with time and finally approach zero. The possible reasons are as follows: 1) After adsorption for a period of time, the number of gas molecules in the container decreases, and the molecular motion slows down. The gas molecules are far away from the adsorbent need to move to the vicinity of the adsorbent for a longer time, resulting in the decrease of the content of decomposition products. 2) The number of adsorption holes on the
adsorbent is limited. After absorbing a certain amount of SO2 and SOF2 gas, the adsorption capacity will decrease. Therefore, with the increase of the use time of the adsorbent, the adsorption capacity shows a downward trend. 3) When the adsorbent adsorbs a certain amount of SO2 and SOF2 gas, it will definitely reach saturation state, or completely absorb SO2 and SOF2 gas [6].

5. To summarize
In SF6 switching equipment, the decomposition product characteristic components of internal insulation defects can be generated in the process of surface insulation surface, mechanical cracks, abnormal heat, surface discharge of insulation rod, particle discharge of insulation parts, crack discharge and abnormal heat. The mechanism of decomposition products in partial discharge defects and abnormal heating defects is introduced. The influence of partial discharge defect, abnormal heating defect and adsorbent on the decomposition products was analyzed.

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