A potential fault of circuit breaker found using SF₆ decomposition products detection

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Abstract. A 126kV circuit breaker was found to have latent fault by SF₆ decomposition product detection method. It was found that the sulfur hexafluoride gas decomposition products of the circuit breaker contained a large amount of CO gas, a certain amount of SO₂ and H₂S, and a small amount of HF gas. The characteristic components and their contents of the decomposition products were analyzed, it is preliminarily concluded that there is insulation material fault in the circuit breaker, and the potential fault is further confirmed by the disassembly inspection that the MoS₂ lithium base grease is overcoated at the metal tie rod joint.

1. Introduction

SF₆ gas is widely used in electrical equipment as a good insulation and arc extinguishing medium. Under normal operating conditions, the SF₆ gas is not broken down and doesn’t react with other materials. But under the action of discharge or high temperature, SF₆ gas will be decomposed and react with water, oxygen, metal vapor and other impurities in SF₆ gas to form many sulfur-containing and fluorine-containing compounds[1]. Grease is widely used in electronics, electric power, steel and automobile industries. It is a kind of semi-solid lubricating material with plasticity[2-4]. Grease is an important component of industrial lubricants. Its components are mainly base oil, thickener and additive. The main functions of grease include protection, sealing, damping, noise reduction and friction reduction[5-7]. The lubrication state of the circuit breaker must be strictly controlled. The lubricant not only affects the mechanical properties of the operating mechanism, but also greatly affects the electric field strength[8]. A small amount of the gas is also released when the organic insulating material in the equipment is cracked. The type and content of decomposition products are directly related to the type, location and degree of failure[1].

2. Fault detection

During the general test of SF₆ electrical equipment by State Grid Corporation of China, it was found that the decomposition product content of a 126 kV circuit breaker was abnormal, the decomposition products of SF₆ gas of the circuit breaker were detected by electrochemical sensor method, detection tube method and gas chromatography method, and the results are shown in table 1.

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Table 1. Content of SF₆ gas decomposition products of abnormal circuit breaker under different detection methods (unit: μL/L).

| Detection method         | SO₂ | H₂S | CO   | HF  |
|--------------------------|-----|-----|------|-----|
| Electrochemical sensor method | 15.0 | 10.1 | 103.2 | 3.3 |
| Detection tube method    | —*  | 11.0 | —    | 6.0 |
| Gas chromatography       | 16.5 | 10.6 | 105.8| —   |

Note: ‘—’ means unmeasured.

As shown in table 1, the gaseous decomposition products measured by the three methods contain large amounts of CO gas, a certain amount of SO₂ and H₂S, and a small amount of HF gas.

In order to view the gas decomposition products of the circuit breaker at different time intervals, three detection methods were used to measure the gas decomposition products of the circuit breaker at intervals of 8 hours and 12 hours respectively, the results are shown in table 2.

Table 2. Content of SF₆ gas decomposition products of abnormal circuit breaker with different interval times (unit: μL/L).

| Detection time    | Detection method            | SO₂ | H₂S | CO  | HF |
|-------------------|-----------------------------|-----|-----|-----|----|
| 8-hour intervals  | Electrochemical sensor method | 14.2| 18.2| 105.5| 4.1|
|                   | Detection tube method        | —*  | 10.0| —   | 6.6|
|                   | Gas chromatography           | 16.3| 11.2| 105.5| — |
| 12-hour intervals | Electrochemical sensor method | 15.5| 19.5| 100.5| 3.3|
|                   | Detection tube method        | —   | 14.0| —   | 5.0|
|                   | Gas chromatography           | 17.4| 10.3| 106.4| — |

Note: ‘—’ means unmeasured.

Combining the results of the three measurement methods in tables 1 and 2, it can be seen that the gas decomposition products of the abnormal circuit breaker contain a large amount of CO gas in addition to SO₂ and H₂S and a small amount of HF, this shows that the abnormal circuit breaker has a latent fault. It is judged preliminarily that this circuit breaker latent fault is the insulation material fault. The types of latent faults may be nozzle ablation, insulation material failure, excessive grease and so on, according to a large number of simulation test results, on-site testing of circuit breakers and analysis of the testing results of accident equipment.

3. Cause analysis of potential fault of circuit breaker

By referring to the results of a large number of simulation experiments and comparing the results with the general measurement data of normal operation equipment, the content of CO gas component is seriously abnormal compared with other characteristic decomposition products, therefore, the CO was studied as the main characteristic decomposition product of the circuit breaker. The materials that can cause CO content abnormal in SF₆ decomposition products in circuit breaker mainly include lubricating grease, nozzle material polytetrafluoroethylene and insulation rod material epoxy.

The grease used in the SF₆ circuit breaker is molybdenum disulfide grease. The main components of molybdenum disulfide grease are base oil and thickener, the base oils are mainly substances containing carbon and oxygen such as polyethylene glycol, synthetic esters, perfluorinated polyethers and polyphenylene ether, the thickener consists mainly of mineral oils thickened with lithium soap containing hydroxy fatty acids and molybdenum disulfide additives with excellent resistance to abrasion and extreme pressure; the epoxy material is similar to polyethylene glycol in fact.

Due to the symmetry of the molecular structure and the stronger electronegativity of the fluorine
atom, the polytetrafluoroethylene is relatively stable under the action of light, heat and electric field, according to the structural characteristics and properties of the organic compounds. The main components of molybdenum disulfide grease and epoxy are substances containing carbon and oxygen, which are less stable under arc action (high voltage and high temperature) than polytetrafluoroethylene. Lithium molybdenum disulfide grease and epoxy are more prone to chemical reaction than polytetrafluoroethylene at the same conditions. Polytetrafluoroethylene, molybdenum disulfide grease and epoxy may react to form CO at high voltage and high temperature because of SF₆ gas contains small amounts of O₂ and H₂O.

Under the condition of arc discharge, the nozzle of the arc quenching chamber of the circuit breaker will be ablated, causing the polytetrafluoroethylene to react. A lot of arc discharge experiments have been done in this project for nozzle ablation fault. It is found that a certain amount of SO₂ can be detected in the decomposition products of SF₆ gas under different interrupting current conditions, but basically no CO. Taking the arc discharge experiment with breaking current of 18.7 kV as an example, the chromatogram of SF₆ gas decomposition products is shown in fig. 1.

![Chromatogram of SF₆ gas decomposition products at 18.7 kV breaking current.](image)

In fig. 1, the two chromatographic peaks are SF₆ and SO₂, and the others are impurity gases of the new SF₆ gas. No large amount of CO is formed in the decomposition products. In the detection of the decomposition products of the circuit breaker, a large amount of CO was detected, so the fault of the circuit breaker can basically eliminate the nozzle ablation failure. Therefore, the source of carbon in the CO may be from molybdenum disulfide grease and epoxy grease for the faulty circuit breaker.

4. Analysis on disassembly inspection of circuit breaker
In order to further study the fault defect types of the circuit breaker, the circuit breaker was returned to the factory and disassembled for inspection. The following phenomena are found in the circuit breaker.

(1) There is a large amount of SF₆ solid state products in the failure phase porcelain bottle of the circuit breaker, as shown in fig. 2 below. The large amount of white powder on the inner wall of the porcelain bottle is SF₆ solid state product.
Fig. 2 A large amount of SF₆ solid products in the failure phase porcelain bottle.

(2) There is a layer of carbon black substance on the contact of the fault phase terminal, the metal surface of the pressure cylinder and the pull rod of the fault phase of the circuit breaker, which is in sharp contrast with the other two phases. The insulation pull rod of the other two phases has no ablation phenomenon as shown in fig. 3 below. In the diagram, the middle phase is the fault phase and the two sides are the normal phase. As can be seen in the diagram, the surface of the middle phase is obviously blackened.

Fig. 3 Moving end contact assembly (fault phase in the middle and two other phases on the left and right sides)

(3) There is a large amount of carbon black attached to the arc-starting contact at the static end of the fault phase, as shown in fig. 4. The carbon black appendages are shown in the figure as shown by the arrows.
Fig. 4 There is a black attachment on the faulty phase arc starting contact.

(4) There is a large amount of carbon black colloid on the base of the phase pressure cylinder at the fault moving end contact, as shown in fig. 5 below. The arrows indicate a large amount of carbon black colloids attached to the bottom of the cylinder.

Fig. 5 Failure phase pressure cylinder.

(5) Under normal circumstances, the metal tie rod joint of the bottom of the pressure cylinder should be coated with MoS$_2$ lithium-base grease, the function of MoS$_2$ lithium-base grease is to lubricate the opening and closing operation of the circuit breaker. It was found that the coating of MoS$_2$ lithium-base grease on the connection of metal tie rod was over-coated.

5. Conclusion

(1) The results of detecting abnormal circuit breakers are consistent by electrochemical sensor method, detection tube method and gas chromatography method. The SF$_6$ gas decomposition products of the abnormal circuit breaker also contain a lot of CO gas in addition to SO$_2$, H$_2$S and HF. The latent fault was judged preliminarily to be insulation material fault.

(2) The source of carbon in the CO of the fault circuit breaker may be the molybdenum disulfide grease and the epoxy grease through the analysis of the cause.
(3) A large amount of SF₆ solid state product was found in the porcelain bottle of the fault phase of the circuit breaker, a large amount of carbon black adhesive substance was found on the static arc starting contact of the fault phase, and a large amount of carbon black colloid was found on the base of the phase pressure cylinder of the fault dynamic end contact, the coating of MoS₂ lithium-base grease at the connection of metal tie rod has serious over-coating phenomenon.

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