Summary of GIS fault diagnosis methods

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Abstract

In order to distinguish whether there is a hidden trouble in the gas insulated closed switchgear (GIS), this paper carries out targeted detection on GIS . Firstly, aiming at the filling gas in GIS, its basic characteristics and special characteristics when different faults occur are analyzed. Based on the GIS faults data in the national network, several types of faults occurring frequently in GIS operation processes are summarized. From the chemical point of view, the decomposition products produced in SF6 of GIS internal faults were detected, such as gas chromatography, detection tube method and so on. From the physical point of view, GIS surfaces are tested, such as ultrasonic detection, infrared imaging detection and so on. The detection principles of different methods are described.

Keywords

Fault type, detection method, gas decomposition, infrared imaging detection, ultrasonic detection.

1. Introduction

Sulfur hexafluoride ($SF6$) gas is a non-toxic, colorless, odorless, non-flammable stable gas (normal temperature, normal pressure), with excellent insulation and arc extinguishing ability; in recent years, $SF6$ gas with its excellent insulation and extinction Arc performance is widely used in power system ultra-high voltage and ultra-high voltage power equipment, such as gas insulated switchgear, gas insulated transmission line and gas insulated transformer[1]; $SF6$ gas has stable chemical properties and strong electronegativity. However, when power equipment fails, $SF6$ gases will react with other impurities (such as water and air) mixed in them to produce highly toxic and corrosive gas decomposition[2]. Although the protection of $SF6$ power equipment is becoming more and more stringent, accidents in the use process can't be completely avoided[错误!未找到引用源。]. Electrical measurement, ultrasonic method and UHF method can be used to diagnose the discharge fault of GIS . However, due to various interference in the field, the electric measurement and ultrasonic method are vulnerable to electromagnetic noise interference in the field. UHF method has strong anti-interference ability, but it is difficult to quantitatively analyze the discharge, and it is difficult to make an accurate judgment of the insulation operation state[4]. For the Partial Over Thermal(POT) fault of $SF6$ equipment, although the surface temperature can be directly measured by infrared to judge[5], when POT occurs inside $SF6$ equipment, the surface temperature of the fault is affected by many parameters such as the thermal resistance coefficient of $SF6$ gas, the distance between the heat source and the surface of the equipment shell, and so on. Therefore, it is not possible to directly determine the internal local overheating temperature by measuring the surface temperature of 23 equipment by infrared method. Nor can real-time monitoring be carried out by the electrical, magnetic, optical and ultrasonic signals stimulated in the discharge process[6].

Starting from some common types of faults, this paper explores the causes of faults, and focuses on the corresponding detection methods and their detection principles.

Organization of the Text

2. SF6 equipment common fault types

2.1 SF6 equipment common fault statistics

GIS has always been considered as a high voltage electrical equipment with little or no maintenance, but according to the statistics of the International Great Grid Conference (CIGRE), its failure rate is much higher than that recommended by IEC standards. Among them, the probability of insulation failure is the largest. According to the statistics of State Grid Corporation[7], from 2012 to 2017, a total of 2897 intervals of defects occurred in *GIS* equipment of 72.5 kV and above in the State Grid Corporation system, and 2867 intervals of defects were eliminated in practice, with a vacancy rate of 99.0%. After 2015, 192 unplanned outages of equipment were caused by its own reasons. Among them, 201 intervals per time of critical defects resulted in 85 unplanned outages of the equipment itself, with a vacancy rate of 100%; 452 intervals per time of serious defects resulted in 103 unplanned outages of the equipment itself, 451 intervals per time of actual elimination of defects, with a vacancy rate of 99.8%; 2244 intervals per time of general defects, 2215 intervals per time of actual elimination of defects, with a vacancy rate of 98.7%. The cause of the failure is shown in Figure 1.

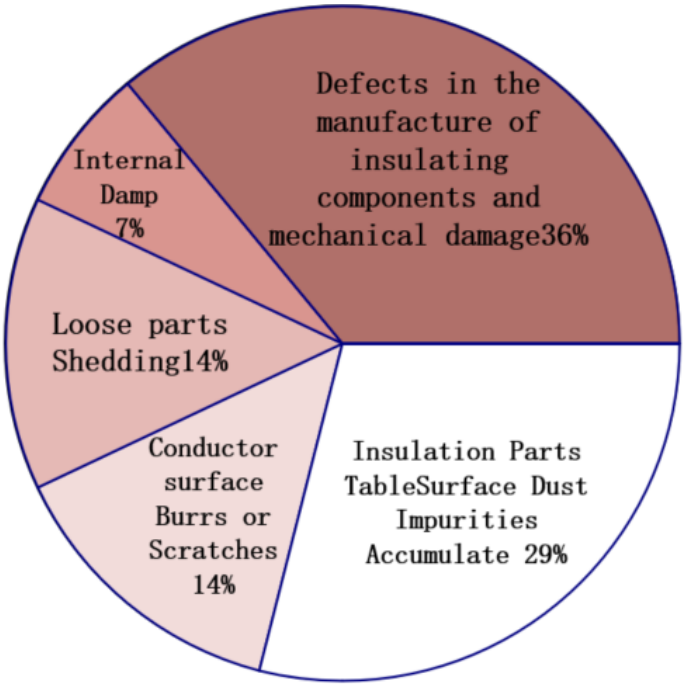

Figure 1 GIS insulation fault cause analysis diagram

2.2 SF6 equipment insulation fault

In the process of manufacture, transportation, installation, operation and overhaul of *SF*6 gas insulating equipment, due to production process, mechanical vibration, installation negligence, movement wear and inadequate maintenance, it will inevitably cause different degrees and types of insulation defects in *SF*6 gas insulating equipment. According to the fault nature of the *SF*6 equipment, the literature [8] divides the faults of *SF*6 gas-insulated equipment into discharge faults, overheat faults and mechanical faults, while mechanical faults often manifest themselves in the form of overheat faults and discharge faults. Therefore, only research on discharge faults and overheat faults is required.

2.2.1 Discharge failure

According to the above research, the main reason for the discharging insulation fault is that there are various defects in *SF*6 gas insulating equipment, which distort the electric field inside the equipment and eventually lead to various insulation faults (mainly induced discharging faults). According to the types of defects, insulation defects mainly include: free conductive particles, metal protrusions,

insulator defects and suspended potential bodies[9]. Under the action of a series of external factors, such as electrical stress, chemical corrosion caused by various decomposition products and mechanical vibration, these insulation defects will develop and intensify, and eventually form insulation failure, resulting in power failure of equipment.

2.2.2 Overheating fault

After $SF6$ gas insulating equipment is put into operation, there will inevitably be defects such as bad contact, saturation of magnetic circuit, magnetic short circuit and various discharges in its interior. If these defects can't be handled in time, the thermal stability of the defect will be destroyed, which will cause $SF6$ gas insulating equipment local overheating phenomenon, and may cause local overheating failure in serious cases.

2.2.3 Mechanical failure

In substation interior, besides discharging fault, mechanical fault is also one of the main causes of accidents. Literature [10] states that typical mechanical defects may be caused by faults in manufacturing, transportation and assembly, including loosening of corona shield, undetected scratches and poor contact of switches. Among them, some mechanical defects can't show obvious fault characteristics in the acceptance and early operation of $SF6$ equipment, but with the accumulation of running time of equipment, it may lead to major electrical accidents.

3. Detection method and principle

For the above mentioned $SF6$ kinds of equipment fault types, the detection methods adopted are mainly divided into two kinds: one is based on chemical method to detect the products decomposed by $SF6$ when the fault occurs, and the other is based on physical method to detect some physical phenomena when $SF6$ equipment fails.

3.1 SF6 gas decomposition product detection

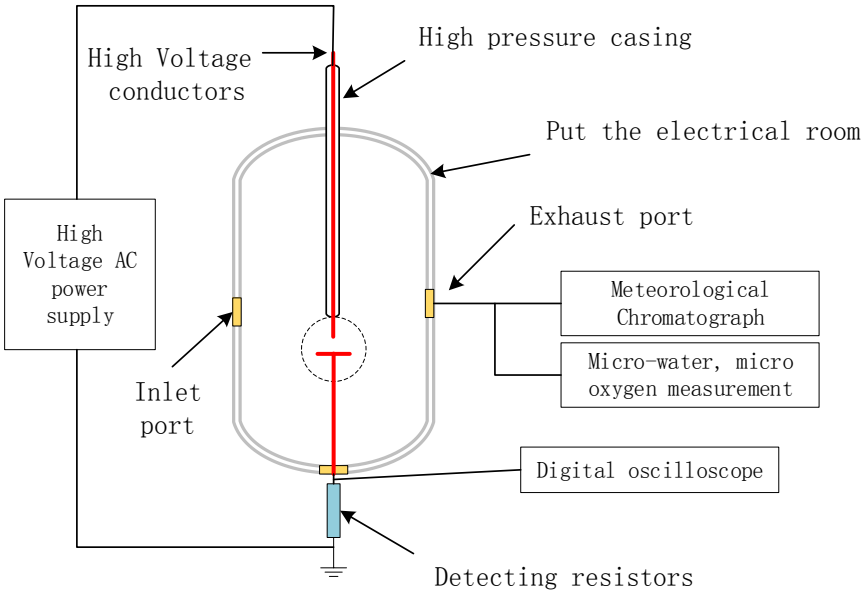

Figure 2 $SF6$ decomposition experimental device

In order to maintain the stability of GIS equipment in the power system, the preliminary fault diagnosis of the insulation state of the equipment by $SF6$ gas decomposition components is a key step[错误!未找到引用源。]. Due to the early latent insulation failure inside the GIS equipment, the pin-plate type discharge and local overheating of different forms and strengths are often accompanied, and the local strong electromagnetic energy and local high temperature generated will cause the $SF6$ insulating gas medium to decompose to different degrees. Generate various SF_X (x=1,2,3,4,5). If there are traces

of H_2O and O_2 at the same time inside the $SF6$ gas-insulated equipment, the decomposition products will further react with them to form component gases such as SO_2F_2, SOF_2, SO_2, HF and H_2S [12-15]; Insulating solids and metallic materials, etc. also produce carbon-containing components such as CO_2 and CF_4 [15]. $SF6$ decomposition device shown in Figure 2.

3.1.1 Gas chromatography

Literature [16] Based on the traditional judgment method of laboratory gas chromatography detection, combined with semiconductor high and low temperature cold trap device to eliminate the influence of $SF6$ gases and concentrate some $SF6$ decomposition compounds at low temperature, the concentration of $SF6$ decomposition products reaches the detection limit, which is a great step forward for further exploration and Research on the detection of $SF6$ gas decomposition products. Literature [17] Preliminary judgment of partial discharge type was made by analyzing $PRPS$ and $PRPD$ patterns of partial discharge signals detected by UHF method. Combined with the oscilloscope, the time difference of signals received by sensors at different locations is analyzed to realize the localization of partial discharge source and the elimination of field interference source. After preliminary determination of defect location, $SF6$ decomposition components were analyzed by helium ion gas chromatography. Gas chromatography uses inert gas as mobile phase to monitor sulfides, halides and electronegative compounds in samples by means of thermal conductivity detection, flame photometric detection and electron capture. The method has high accuracy and is widely used in laboratory gas test. In the field detection of $SF6$ in electric power industry, gas chromatography based on thermal conductivity detection principle is usually used to monitor the composition of $SF6$ decomposition products, which usually has good detection effect for CF_4 and CO_2 gases. However, because the monitoring method is time-consuming and the test results are greatly affected by the environment, it is not often used in the detection of decomposition products of power equipment $SF6$. Figure 3 illustrates the principle of gas chromatography.

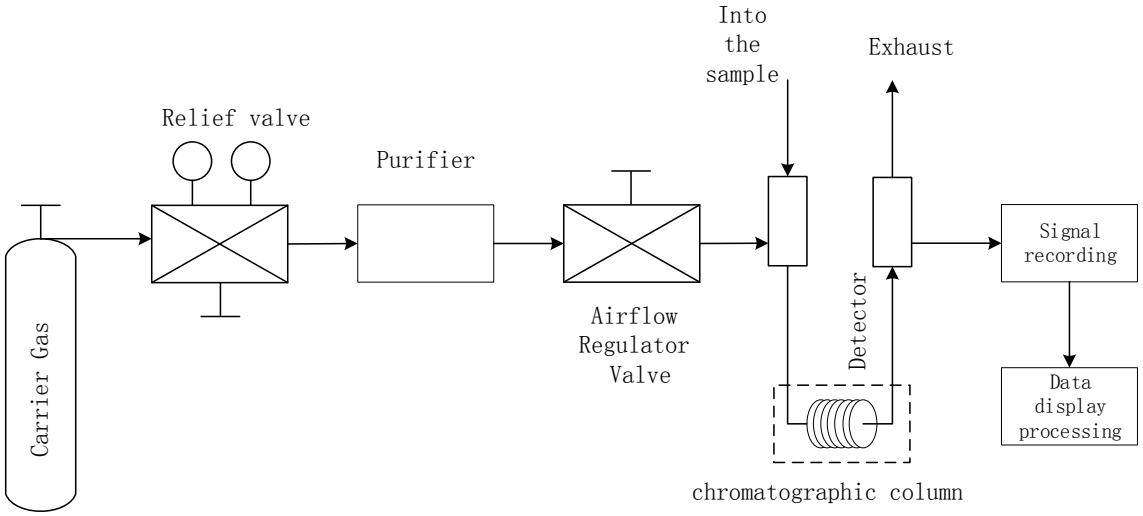

Figure 3 Gas chromatograph schematic

3.1.2 Infrared absorption spectroscopy

Literature [18] Through the analysis of $SF6$ standard samples of gas decomposition, SiF_4 of them were detected by Fourier transform infrared spectroscopy, and their qualitative and quantitative analysis were carried out. The equipment has been put into operation for a long time, and the complex reaction process takes place inside and around $SF6$. Different failure types will produce different decomposition substances. The presence of SiF_4 and its content change can largely reflect the degree of damage inside the equipment. Infrared absorption spectrometry is based on the principle that part of

infrared light is absorbed by gas when infrared light passes through gas. The infrared absorption spectrum of sample gas can be obtained by experiment. The corresponding absorption peaks and characteristic frequencies can be found by the peaks appearing in the infrared absorption spectra of the gas. The absorption effect of gas can be used to detect the content of $SF6$ decomposing gases. This detection method does not need to separate the mixed gas, needs fewer gas samples, and the detection results of multiple gases can be completed simultaneously. The test process is short, so it can be used in on-line insulation monitoring system of power equipment. However, because the absorption peaks of $SF6$ decomposed gases may be close and the detection sensitivity is low, the accuracy of the test data is limited.

3.1.3 Detection tube method

Literature [19] Taking the detection of H_2S gases as an example, when the gas containing H_2S reacts with the detector through the detection tube, it produces brown substance. The length of the discolored substance corresponds to the content of H_2S, so the content of H_2S gases can be detected. Different gas detection tubes use different detectors, but the measuring principle is the same. In the field measurement of decomposition products of power equipment $SF6$, the gas can be directly put into the detection tube to control the flow rate of the gas, complete the measurement within a specified time, and read the length of the discoloration section to get the content of the gas tested. This method has the advantages of large measurement range, simple measurement method, fast conclusion and easy to carry. It is widely used in the field of power equipment fault diagnosis. However, the detection accuracy of this method is not high, so it is mostly used in qualitative experiments and preliminary quantitative measurements. The detection tube method is based on the principle of chemical color reaction and sludge adsorption effect. It can measure the content of SO_2、HF、H_2S、CO_2 and other substances. Inside the detection tube is a detector which can react with the gas to be measured. When it reacts with the gas, the color will change. The gas content is measured by observing the measurement on the glass tube.

3.1.4 Electrochemical gas sensor method

The method of electrochemical gas sensor is to obtain the composition and content of the gas to be measured by using the current passing between the two electrodes of the sensor is proportional to the content of the gas after the chemical reaction of the gas under the action of catalyst. This method has fast detection speed and convenient data processing, and has been widely used in live detection of power equipment. However, the sensor used in this method reacts with the gas to be measured, so the service life is not long, and there is a phenomenon of zero drift, so the instrument needs to be calibrated frequently in the application process[20].

4. Ultrasonic testing

Literature [21] Aiming at an abnormal sound in the gas chamber of the combined electrical apparatus in substation, the diagnostic live detection is carried out by using the ultrasonic partial discharge detection method, and the cause of the fault is determined. Literature [22] expounds the principle of using ultrasonic method to detect electrical equipment fault diagnosis, gives some typical diagrams of ultrasonic method to detect discharge faults of equipment, and gives relevant application examples to prove that this method can detect corona discharge, suspension discharge and free metal particles more sensitively. Because there are gas and solid medium in GIS equipment, only longitudinal wave is propagated in gas medium, and longitudinal wave and shear wave can be propagated in solid medium. Therefore, the ultrasonic propagation path in GIS is very complex. The acoustic wave propagating along $SF6$ gases has a slow propagation speed and a large signal attenuation, which increases with the increase of frequency. Because ultrasound is a kind of mechanical wave, the detection method is not disturbed by the electrical circuit, and has strong anti-electromagnetic interference ability. At the same time, because of the slow propagation speed of acoustic wave, it is more conducive to the location of partial discharge source. However, the sensitivity of the detection method is largely affected by the

propagation path and attenuation, and the sensitivity of the ultrasonic sensor is not very high. At present, it is mainly used as an important supplement to UHF detection method[23].

4.1 UHF detection method

UHF detection method is a partial discharge detection method. The frequency band detected by this method is $300MHz \sim 3GHz$. At the same time, the structure of *GIS* is coaxial, which is conducive to the propagation of electromagnetic wave[24]. Because electromagnetic wave can leak out at the edge of the discontinuous impedance of the basin insulator, it can be measured at the outer insulation of *GIS* basin insulators. This test method mainly uses UHF sensor to receive UHF signal from *GIS* internal insulation defect locations, so as to realize *GIS* partial discharge detection. UHF method has many advantages, such as good anti-jamming characteristics, high sensitivity and power source location, because the frequency band of the detected signal is high and the frequency band of the interference signal caused by corona discharge is low. At present, this method is mainly used in the field.

4.2 Light detection

Partial discharge produces charged particles, and charged particles emit photons in the process of recombination. The detection of *GIS* partial discharge can be realized by optical sensor. However, because the location of partial discharge can't be determined in advance, and the internal structure of field *GIS* is complex, the optical signals generated by partial discharge may pass through multiple refractions and reflections to reach the optical sensor, which requires the selection of observation window with good transmittance and reasonable measurement location, and the emergence of "dead angle", which requires a large number of optical sensors with high cost. At present, this method is only in the laboratory research stage, and has not been applied in the actual field for the time being[25].

4.3 Ultraviolet imaging detection technology

Ultraviolet imaging detection method is a live detection method. The basic principle is as follows: Ultraviolet imager can observe ultraviolet light whose wavelength range is $40ns \sim 400ns$ which can't be seen by human eyes outside the visible range, and then present it in the form of visible light, so that the position and intensity of luminescence can be determined, and the electric field distribution around the charged equipment can be further analyzed. In the case of non-contact, the discharge around the high-voltage equipment can be observed intuitively, which provides a new diagnostic means for live detection. In addition, the detection can be carried out in the daytime. But on the other hand, because ultraviolet photons can not penetrate the metal shell of electrical equipment, it is necessary to open a separate observation hole when using ultraviolet imaging detection technology to observe the insulation defects inside the electrical equipment. From this point of view, the application of this technology to discharge detection of *GIS* equipment is limited[26].

4.4 Infrared imaging detection technology

The principle of infrared detection technology is different from that of ultraviolet imaging detection technology. Ultraviolet imaging can simply show the distribution of electric field near the conductor, and the defects found are caused by the anomaly of electric field in space. Infrared imaging can reflect the temperature field near the subject, and the defects found are caused by temperature anomalies. The infrared wavelength ranges from 25 ns to 750 ns. According to the blackbody radiation theory, if the humidity of the sample is higher than absolute zero, it will emit infrared radiation to the surrounding space uninterruptedly and spontaneously. According to the existing reports and known examples, this method can detect the thermal faults of *GIS* equipment, and the thermal faults are closely related to the degree of deterioration and structural location, and the relative comparison method is often used to judge the thermal faults[27].

Literature [29-31] uses the absorption ability of $SF6$ gases to $10.3\sim10.7\mu m$ -band infrared light, and detects whether $SF6$ gases leak or not by treating the irradiation of detection equipment with infrared equipment.

5. Application prospect

Nowadays, with the rapid development of science and technology and the continuous progress of power system, *SF*6 fully enclosed combinations have become very important components of power system because of their good insulation performance, small size and simple installation and maintenance. It is the best choice for substations with limited installation space[31]. However, *GIS* failures occur from time to time, which will cause huge economic losses and adverse effects. Therefore, fault detection of *GIS* equipment in operation, early detection of *GIS* internal security risks and timely removal, can effectively prevent *GIS* safety accidents[32].

At present, the research on condition assessment and condition-based maintenance of *GIS* equipment is not mature enough, and its errors need to be further improved. We should improve our technology on the basis of learning advanced technology from other countries and proceed from the actual situation of our country, and further guarantee the operation of electrical equipment.

6. Conclusion

With the development of technology, the fault detection technology of *GIS* equipment has become more and more mature, and the accuracy and accuracy that can be achieved are also getting higher and higher. Mainstream detection methods are divided into direct detection of *SF*6 gases and indirect detection of *SF*6 gases decomposition products in the event of failure. Direct detection method can quickly detect whether there are *SF*6 gas leaks, which has strong applicability, but the current technology level for *SF*6 gas leaks requires higher, and can't respond to small leaks in time. The indirect detection method can achieve high detection accuracy, but the decomposition products produced by different fault types are different, and the universality of this method is very low. In order to give consideration to accuracy, rapidity and universality, it is necessary to find a balance between them to meet the requirements.

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