Analysis of common faults in Gas Insulated Substation

Yuhang Ma*
North China Electric Power University, Hebei, China

*Corresponding author e-mail: 1607508364@ncepu.edu.cn

Abstract. This paper makes a statistical analysis of the common faults of GIS equipment, and discusses the causes, hazards and maintenance methods of the four common faults: SF6 gas leakage, SF6 gas micro water exceeding standard, partial discharge caused by internal insulation breakdown and component defects.

1. Introduction
GIS (gas insulated substation) is the abbreviation of gas insulated substation. In the gas insulated substation, most of the electrical equipment are directly or indirectly sealed in the pipe tree composed of metal pipes and sleeves, and no switches, lines and terminals can be seen from the outside. SF6 gas is used as the insulating medium inside the pipeline tree, and all high voltage electrical components are sealed in the grounding metal cylinder. It is a high-voltage distribution device composed of circuit breaker, bus, disconnector, voltage transformer, current transformer, arrester and bushing.

The following figure 1 is the typical interval profile of GIS [1]

![Figure 1. Typical interval profile of GIS](image_url)

**Figure 1.** Typical interval profile of GIS
CB: circuit breaker CT: current transformer DS: disconnector ES: earthing switch
BUS: main bus Vt: voltage transformer CHD: cable terminal
HSEs: fast earthing switch EDS: three position isolating switch
Compared with the ordinary substation, GIS has many advantages: (1) the failure rate of GIS is one order of magnitude lower than the traditional open substation equipment, and the maintenance cycle of the equipment can be extended. The traditional overhaul cycle of 110kV substation is generally about 3 years, once a year; while the overhaul cycle of GIS Substation is generally about 10 years, the longest can be extended to 20 ~ 25 years. (2) Small volume, saving land resources. (3) The installation of GIS equipment is convenient. Generally, it is directly transported to the site after the factory is assembled, and there is no need to reassemble. Because of these advantages of GIS equipment, its application in power system is more and more widely. During the 11th Five Year Plan period, the dedicated quantity of circuit breaker equipment under the jurisdiction of State Grid Corporation of China has maintained a rapid growth. The installed quantity of circuit breakers (including GIS) of 126kV and above has increased by 55.8%, especially the increase of GIS, with an average annual growth rate of 34.5%. The installed proportion has increased from 11.5% at the beginning of 2006 to 23.4% at the end of 2010. Therefore, in the near future, GIS equipment will replace other switchgear and become the mainstream of substation electrical equipment.

2. Fault analysis of GIS

2.1. "Bathtub curve" of GIS fault

Like other power system equipment, GIS equipment in the whole service period, there is an objective statistical law between the number of failures and the use time. Figure 2 shows the change curve of the statistical probability of GIS equipment failure with the years of operation, also known as "bathtub curve". From the "bathtub curve", we can see that the failure rate is very high in the early failure period, mainly due to some problems in the process of manufacturing, transportation, installation and commissioning. Then the accidental failure period drops to a certain minimum value, during which the operation and maintenance are an adaptive process. With the solution of the equipment exposure problem, the failure rate of the equipment gradually decreases, and the minimum value is maintained for most of the service life of the equipment. Finally, after GIS aging, the failure rate of loss failure period increases gradually. Therefore, the operation year is an important factor to determine the status and remaining life of GIS.

![Figure 2. "bathtub curve" of GIS fault](image-url)
2.2. Fault types of GIS

GIS is equipped with important electrical equipment, which can operate reliably only under certain conditions. Statistics show that the main components causing GIS unplanned outage are: grounding switch, disconnector, circuit breaker, bus, Pt, CT, lightning wire, bushing and insulation structure device. The common fault types of GIS are analyzed as follows:

Based on the equipment tracking and professional summary analysis report of Baoding power supply company for three consecutive years in 2012, 2013 and 2014, the defects of GIS are counted [2]. According to the classification of the causes of defects, the summary is shown in Figure 3.

![Figure 3. Tracking table of causes of GIS equipment defects in Baoding area from 2012 to 2014](image)

It can be seen from Figure 3 that SF6 gas leakage fault and SF6 gas micro water exceeding the standard are the most common, and the occurrence frequency is the most common. Although the frequency of partial discharge caused by insulation fault is very small, it has the greatest impact. It will cause GIS equipment outage for maintenance. The outage scope is the largest, the maintenance process is long, and generally lasts for 3-5 days. Therefore, the outage time is the longest, which has the most profound impact on power supply of power system.

In addition, the author also collected the types and quantity proportion of GIS defects in Guangdong power grid in 2009. According to the data in literature [3], the types and quantity proportion of GIS defects are shown in Figure 4.
Figure 4. Statistical table of GIS defects of Guangdong power grid in 2009

As can be seen from Figure 4, SF6 gas leakage fault and circuit breaker, disconnector, grounding switch and other component defects are the most common. Therefore, this paper will introduce the treatment methods of SF6 gas leakage, SF6 gas micro water exceeding standard, partial discharge caused by internal insulation breakdown, and component defects.

2.3. SF6 gas leakage fault
For example, the statistical analysis of GIS fault causes in Baoding and Guangdong areas shows that SF6 gas leakage fault is the most frequent fault of GIS equipment. Once a large number of SF6 leaks, it will cause serious consequences such as insulation breakdown of equipment, damage to electrical equipment, toxic decomposition products, harm to human health and environmental pollution. In the process of dealing with this fault, a lot of power outage time and manpower and material resources are spent, which has become a major factor affecting the normal operation of the equipment. The common causes of SF6 gas leakage include: material quality problems, equipment assembly problems, density relay problems and equipment aging problems. [4] SF6 gas leakage points are also different, including weld leakage, shell sand hole leakage, flange joint surface leakage and other leakage points.

For many years, scholars and experts at home and abroad have done a lot of research on the detection of SF6 gas leakage. The common SF6 gas leakage detection technologies are as follows: absorption method, tracer method, gas infrared absorption imaging, leak detector, laser photoacoustic spectrum detection, soap bubble method, bandaging method, vacuum monitoring, gas infrared radiation imaging, etc.

In order to avoid the frequent occurrence of SF6 gas leakage fault, the product quality and installation quality must be strictly controlled. The selected GIS equipment must be of excellent quality and installed in strict accordance with the standard procedures. In addition, it is necessary to strengthen the inspection and maintenance of equipment, improve the skill level of maintenance and operation personnel, and take effective and reasonable measures to solve the leakage problem.

2.4. SF6 gas micro water exceeding standard fault
High voltage electrical equipment is strict with the micro water content of SF6 gas. When the water content of the gas inside the equipment reaches a certain range, condensation will appear at a lower temperature, which will lead to the decrease of insulation level and the decrease of surface flashover voltage; The presence of water will accelerate the decomposition reaction of SF6 under the action of arc, and produce a variety of highly corrosive and toxic impurities, causing chemical corrosion of equipment...
and endangering the personal safety of workers. Therefore, the micro water control of SF6 gas is very important for the normal operation of GIS. [5]

In order to ensure the safe operation of electrical equipment, relevant departments have formulated clear water content control standards for SF6 gas insulated medium, as shown in the table below.

| Compartment                          | Compartment with arc decomposition products | Compartment without arc decomposition products |
|--------------------------------------|---------------------------------------------|-------------------------------------------------|
| Handover acceptance value            | ≤ 150                                       | ≤ 300                                           |
| Allowable value of operation         | ≤ 300                                       | ≤ 1000                                          |

In order to measure the water content of SF6 gas, micro water test should be carried out. Micro water test actually refers to the humidity measurement of gas in low humidity state. Common micro water test methods include electrolysis method, dew point method and resistance capacitance method.

In the operation process of GIS equipment, the micro water content of SF6 gas is required to be high, and the micro water content up to the standard is a necessary condition for the safe and stable operation of power system. The following methods can be used to ensure the water content of SF6 gas up to the standard: (1) to ensure the quality and purity of SF6 new gas, micro water test should be carried out before charging into GIS equipment, and the quality standard of SF6 new gas in China should be met. (2) Control the treatment of insulating parts. The insulating parts shall be sealed and packed immediately after drying treatment, and the insulating parts not assembled at the installation site shall be stored in the container with dry nitrogen. (3) Do a good job of acceptance. Carefully observe whether each gas chamber is well sealed, and ensure that dry nitrogen or SF6 gas with 0.03mpa pressure is filled, so as to avoid moisture and damage to internal parts of each gas chamber of GIS equipment during transportation. (4) The key to ensure the safety of SF6 circuit breaker equipment is to prevent air leakage and monitor the micro water content of SF6 gas. In order to maintain the safe and stable operation of the equipment, the water content data in the past are compared and analyzed every specified time.

2.5. Partial discharge caused by internal insulation breakdown

When there are some insulation defects in GIS equipment, the internal electric field will be distorted, resulting in high local electric field. When the insulation strength of SF6 gas insulation medium is exceeded, partial discharge (PD) will occur. In fact, every PD will reduce the electrical strength of GIS insulation more or less, especially the long-term or strong PD will make the insulation of GIS equipment failure and aging quickly, even serious failure. Because the consequences of insulation breakdown are more serious, and the impact on power failure is more bad, so it is widely concerned by domestic and foreign power system and experts and scholars [6].

The insulation state of GIS equipment can be known by the light, sound, electricity and other information generated by PD. This detection method is called PD monitoring method. The main PD monitoring technologies include: pulse current method, ultrasonic detection method, ultra-high frequency method, light detection method, SF6 gas decomposition component detection method. In addition, there are periodic monitoring methods for insulation state detection, mainly preventive tests required by relevant regulations, including impact test method, withstand voltage test method, etc.

2.6. Component defects

GIS is a kind of mechanical device, the components constitute the functional mechanism, and the functional mechanisms cooperate with each other to form the whole GIS. The normal operation of GIS is inseparable from a variety of reliable components, so the component defects and faults are common. Such as circuit breaker operating mechanism slow opening and closing, abnormal motor, abnormal
energy storage indication, abnormal pressure build-up of hydraulic mechanism, aging and failure of parts, abnormal vibration of body, etc. [7]. Component defects may be caused by design defects, bad working conditions, operating years and other reasons. GIS equipment will have dysfunction, and then lead to accidents such as maloperation, insulation breakdown, and even equipment damage.

3. Conclusion
Although the failure rate of GIS equipment is lower than that of open substation equipment, through statistical analysis, a part of GIS equipment still fails every year. The common fault types include SF6 gas leakage, SF6 gas micro water exceeding standard, partial discharge caused by internal insulation breakdown and component defects. This paper analyzes the causes, hazards and maintenance methods of these faults, which can be used as a reference for GIS fault maintenance.

Acknowledgments
Finally, I would like to thank the predecessors who have made contributions to the related fields of my research. They have given me great help in writing my thesis.

References
[1] Guo Jie. Application Research of GIS insulation fault diagnosis method [D]. Baoding: North China Electric Power University. May 2013
[2] Hu Jing. Research on the fault analysis of GIS and its maintenance strategies in Baoding electric power distribution company [D]. Baoding: North China Electric Power University. March 2016
[3] Chen pengyong. Gas insulated switchgear running state comprehensive evaluation based on analytical hierarchy process of fuzzy theory [D]. Baoding: North China Electric Power University. March 2013
[4] Leng Guohua. Cause analysis of SF6 gas leakage in combination apparatus. Hongshuihe [J]. 2014,33 (6): 82-84
[5] Yuan Jingjiang. Cause analysis and temporary treatment method of SF6 gas micro water exceeding standard of GIS equipment in 110 kV Bada station. Electrical switch [J]. 2014,1:89-91
[6] Jin Lijun, Liu Weidong. Fault analysis, diagnosis and detection technology in GIS insulation coordination. China electric power [J]. 2002.35 (3): 52-5
[7] Yao Qingqiang, Lehai Road, Xu Zhigang. Fault analysis, treatment and prevention of GIS equipment in 500 kV converter station [J]. Huazhong electric power, 2011, 24 (2): 45-48