Failure Analysis for Disconnector Current Transfer Contact Falling off GIS Gas Chamber

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Abstract. The withstand voltage test of GIS gas chamber disconnector in a new project of transformer substation was not passed. When the cover of the GIS gas chamber was opened, it was found that phase B of “E” rings current transfer contact and the corresponding accessories fell on the basin insulator at the bottom, and the current transfer contact falling off was the main reason for failing the withstand voltage test. Failed phase B & phase A of “E” rings and new sample were analyzed by size and weight test, hardness test, metallographic structure analysis, clamping force calculation and scanning electron microscopy (SEM) analysis. The analysis results show that the thickness value of “E” rings was less than standard value and the weight was not qualified, especially opening width and hardness of failed “E” rings were unqualified and had abnormal microstructure. Unqualified “E” rings and clamp failure caused current transfer contact to fall off.

1. Introduction
GIS is the abbreviation of Gas Insulated metal-enclosed Switchgear. In the GIS devices, all the primary equipment in the substation except transformers, including circuit breaker, isolating switch, ground switch, voltage transformer, current transformer, lightning arrester, connecting bus, cable terminal and incoming and outgoing line casing, are encapsulated in the grounded metal shell, which is filled with sulfur hexafluoride (SF₆) gas at certain pressure as the insulating medium. It is called Enclosed-type Assembled Switchgear in China.

Isolation switch, also known as the isolation knife gate, is a main device in conjunction with a circuit breaker in the substation transmission and distribution lines. Its main function is to ensure the safety of workers during the overhaul of high-voltage equipment. Between the equipment in need of overhaul and other live parts, the isolation switch is used to form an obvious disconnect point and provide sufficient insulation interval for workers [1].

In recent years, some faults often occur in the operation of high-voltage AC isolation switch, which cause great safety hazards to the safe and stable operation of power grid and personal safety. With the increasing loss of power system, people begin to pay attention to the failure of the isolation switch. Isolation switch plays an important role in power system, such as isolating power, changing winding operation mode, separating and closing small load current, and switching operation. Due to its simple operating principle and structure, there is usually no strict overhaul period, and it is generally carried...
out with the main equipment overhaul according to the convention. However, in recent years, with the oil-free transformation of circuit breakers, the transformation of unattended substation and the gradual transition from periodic overhaul system to state overhaul system. As the overhaul cycle of the main equipment is gradually extended, problems with outdoor isolation switches in operation have increased significantly, which directly affect the reliability and security of power supply system [6].

(1) Technical requirements for high voltage AC isolation switch

High-voltage AC isolation switches are used in power grids to combine and separate unloaded circuits and electrical equipment. Its functions mainly include the realization of power transmission and safety isolation. In other words, the normal working current and abnormal (fault) current within a short period of time can be reliably passed in the closing state, while in the opening state, there are insulation distance and obvious disconnect points between contact terminals in accordance with the specified requirements, so that the power equipment on the load side can be safely isolated from the power supply.

The isolation switch has relatively few functions, so its structure is relatively simple, there is no arcing device, and it cannot be used to switch on and off the load current.

High voltage AC isolation switch is outdoor type structure, most of them are operated under relatively harsh outdoor conditions, and exposed to atmospheric environment and vulnerable to environmental and climatic conditions. These factors should be fully considered in the design and manufacture of products to ensure reliable work in rain, wind, ice, snow, dust, cold and heat conditions.

(2) Common failures of the isolation switch

The isolation switch has many defects and faults in the operation of the system, which lead to many problems. There are several common fault types: failure to separate and combine, control circuit failure, heat failure, corrosion failure.

(3) Operation inspection and maintenance of the isolation switch

Inspection work is an effective means to find equipment defects. During the inspection, operators found slightly steam at the contacts for many times. If detected hot spots through temperature measurement in special weather, operators are organized to inspect whether there is steam at the contacts, snow melt and suspension on the equipment, etc. The terminal box and terminal row should be cleaned regularly to remove floating ash, plug holes, remove oil stains from part of the mechanism with acetone, check whether the three-phase power supply and excitation power are normal, and deal with defects such as operation failure. When the equipment is power off any time, the maintenance personnel shall be arranged to carry out antifouling cleaning on the isolation switch supporting porcelain bottles and related independent supporting porcelain bottles. The fouling cleaning agent shall be applied to the porcelain bottles, which can be wiped clean after a few minutes and then several times with wet cloth. The heater shall be reformed and the terminal box and operating box are equipped with sealing rings. In the maintenance, loose terminal, broken safety fuse, small switch in bad contact and poor grounding switch auxiliary contact should be promptly dealt with [2].

2. Fault Description

The fault conditions are as follows: no obvious abnormalities were found in the flat pad and contact laminar, but sliding conductor and long spring were bending, “E” rings were elastic failure. After “E” rings lost its clamping elastic force, it slipped and caused the B phase current transfer contact to drop. The failure sample of B-phase current transfer contact of “E” rings is shown in Figure 1, the normal sample in Figure 2, the failure “E” rings in Figure 3, and “E” rings shown in Figure 4.
3. Size&weight test

According to DIN 6799-2011 《Retaining washers for shafts》 [4], the size of “E” rings was tested:

(1) The opening width of failure B-phase “E” rings was 3.15mm, 13.7% larger than phase A and C (2.72mm), and 14.3% larger than the new one (2.70mm), which was significantly higher than the
standard requirements.

(2) The thickness of the three phases of “E” rings were less than the standard rated value, and the thickness of the new sample was also lower limit specified in the standard.

(3) The weight of phase A and two new samples randomly selected were tested. The weights were 0.0732g, 0.0767g and 0.0735g. The average weight was 0.075g, which did not meet the standard requirements of 0.088g. The results are shown in Table 1.

Table 1. Dimension parameters of “E” rings

| Item                  | Phase B | Phase A | Phase C | New sample | Standard of DIN6799 |
|-----------------------|---------|---------|---------|------------|---------------------|
| Thickness S/mm        | 0.57    | 0.56    | 0.57    | 0.58       | 0.6±0.02            |
| Diameter d3/mm        | 7.19    | 6.84    | 6.82    | 6.72       | 6.3≤D≤7.3           |
| Opening width a/mm    | 3.15    | 2.72    | 2.72    | 2.70       | 2.7±0.04            |
| Qualified             | No      | Yes     | Yes     | Yes        | /                   |
| Groove diameter d2/mm | 3.19    |         |         |            |                     |
| Weight                | 0.075g  |         |         |            | ≈0.088g             |

4. Hardness analysis

The hardness of the failed B-phase “E” rings, phase A&C and new sample of “E” rings were tested by using digital display Rockwell hardness tester [5]. The hardness of the failed B-phase “E” rings did not meet the standard DIN 6799-2011 《Retaining washers for shafts》 requirements and was higher than that other samples. The results are shown in Table 2.

Table 2. Hardness test results of “E” rings

| Item      | Phase B | Phase A | Phase C | New sample | Standard of DIN6799 |
|-----------|---------|---------|---------|------------|---------------------|
| Hardness /HRC | 57  | 53      | 53      | 51.5       | 46-54               |
| Qualified | No      | Yes     | Yes     | Yes        |                     |

5. Metallographic analysis

The hardness of the failed B-phase “E” rings, phase A&C and new sample of “E” rings were tested by using Zeiss AXIO Observer A1m metallographic microscope, the metallographic experiments were carried out on the failed B-phase “E” rings, phase A and new sample of “E” rings. It was found in the test that the metallogenic structure of phase A and new sample of “E” rings was tempered tortenite structure [3]. The failed B-phase “E” rings was the tempered tortenite structure that retained the Martensite phase. Which might be caused by too low tempering temperature or too short holding time. The metallographic structure of the failed B-phase “E” rings is shown in FIG. 5. The metallographic structure of the failed phase A and the new sample are shown in FIG. 6 and 7.
6. Calculation of clamping force
The finite element model of “E” rings was established, as shown in FIG. 8. The finite element calculation of clamping force of the installed “E” rings (phase A), new sample and standard parameters was carried out respectively. The clamping force of the installed “E” rings (Phase A) was 9.69%, lower than that of the standard parameter, and the clamping force of the new sample was 6.46%, lower than the standard parameter. The specific calculation results are shown in Table 3.

| Item                  | Phase A  | New sample | Standard parameters |
|-----------------------|----------|------------|---------------------|
| Clamping force(N)     | 69.33    | 71.81      | 76.77               |
| Compared to standard value | 9.69% lower | 6.46% lower | /                   |

TABLE 3. Finite element calculation results of “E” rings
7. Scanning electron microscopy (SEM) analysis
Scanning electron microscope (SEM, Quanta 250, FEI) was used to detect the samples of phase B and phase A of “E” rings. The second electronic pictures are shown in Figure 9-14. There were fine microcrack defects in the concave shape of B-phase “E” rings.

FIG. 8 Finite element mesh model of “E” rings

FIG. 9 SEM morphology of phase B(50X)
FIG.10 SEM morphology of phase A (50X)
FIG. 11 SEM morphology of phase B at concave surface(400X)
FIG. 12 SEM morphology of phase A at concave surface(400X)
8. Comprehensive analysis
The thickness of f “E” rings was less than the standard specified value, and the weight of each sample was unqualified, resulting in the small clamping force. In particular, the opening width and hardness of b-phase failure samples were unqualified, with abnormal metallographic structure. The obvious unqualified quality made the clamping failure and fell off, resulting in the current transfer contact to drop eventually.

9. Conclusion
The unqualified quality of “E” rings was the main reason of current transfer contact failure. The suggestions are as follows: Quality sampling inspection of moving parts such as “E” rings should be strengthened when GIS equipment is accepted from factory. Meanwhile, The substation shall overhaul the isolation switch according to the maintenance cycle requirements and in combination with each power outage opportunity, including the transformation of the isolation switch operating mechanism box, strengthening the maintenance of equipment and the operator's ability to find faults, in order to reduce the failure rate of the isolation switch, improve the speed of fault elimination, ensure the personal safety of maintenance and operation personnel, and improve the safety factor of the power grid.

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