A Fault Analysis of 750kV Shunt Reactor and Repair Program

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Abstract. Combined with an example of 750kV shunt reactor exception handling, the author used field test inspections and search methods to dismantle the plant and found that the cause of the reactor abnormality was an incident caused by impurities or foreign matter. Combining the historical operation data of the equipment, the analysis and comparison of the reactor's routine inspections and test results are performed. Combined with the simulation calculation of the internal insulation margin of the reactor, the judgment methods and conclusions are given, and the troubleshooting method and flow of the reactor abnormality are proposed, and put forward specific measures to strengthen the state monitoring of the network operation reactor.

1. Introduction
Parallel reactors are widely used in China due to their simple structure, low price and easy maintenance. However, after a long period of operation, shunt reactor failures have occurred many times in recent years. The author analyzes the cause of reactor failure based on the fault condition of a 750kV shunt reactor in a substation in our company.

2. Equipment failure
On February 1, 2015, the on-line monitoring data of XX substation high-voltage reactors found acetylene sudden increase, off-line test of acetylene was 3.2uL/L. After comparison analysis, it was preliminarily judged that there may be low-energy partial discharge inside the reactor.

On the evening of February 1, 2015, the power was cut off. On February 3, the oil discharge inspection was started. The inspection of the box revealed that the four anchor bolts of the internal body were loose, there was a slight discharge between the bolts, and there was black oil on the bolts. Analysis and judgment due to the looseness of the bolts, the potential between the nuts is suspended, causing discharge, resulting in oil chromatographic acetylene exceeding the standard. Reasons for loose bolts: It may be caused by multiple transports of the reactor.

On February 16, 2015, the reactor resumed operation and continued the chromatographic tracking test. The acetylene was 0.86uL/L on the day after the equipment was put into operation, and the acetylene was 1.66uL/L on the second day. The main reason for the occurrence of acetylene after analysis was the body and Acetylene remains in the interior of the insulation and the data is stable.

Off-line testing of acetylene on January 12, 2016 increased from 1.22uL/L on December 30, 2015 to 2uL/L, after which the data stabilized.

On December 8, 2017, the acetylene value increased again, from 2.93uL/L to 3.96uL/L. On December 8th, at 22 o'clock on the evening of December 8, acetylene was 4.13uL/L, and on the 9th,
acetylene was 4.14uL/L. On the 10th, the acetylene was sampled at 4.13uL/L, after which the data stabilized and the product continued to run.

At 14:38 on January 28, 2018, the online data of acetylene increased from 3.29uL/L to 6.56uL/L, and the off-line detection of acetylene increased from 4.05uL/L to 18.37uL/L, and the data of each group were obvious. Increase. At 16:52 on the 28th, the oil chromatography online monitoring acetylene data suddenly increased to 27.07uL/L. At 22:00, the high-resistance sound was abnormal during the special inspection of the operating personnel. At 23:54, the product exited the operation.

3. Grid operation mode
750kV I, II mother Line, 2, 3, 4, 5 string operation, No. 1 main transformer operation; 7081I line, 7093I line, 7094II line, 7082I line, 7097II line, 7089I line operation.
330kV I, II mother Line, 1, 2, 4, 5, 6, 7, 8, 9 string operation; 3967I line, 31065I line, 30926I line, 30927II line, 30928 III line, 30929I line, 30930II line, 30931 line operation, 3971 running I line, 3989II line operation;
66kV single bus operation; 661I reactor No. 6, 6621 reactor No. 7, 6613 reactor No. 6, 6651 station change operation, 6661 No. 1 capacitor bank cold standby;
3511 Station No. 3 operation; 6651 Station No. 1 380V I section operation, 3511 No. 3 station belt 380V II section, III section operation.
DC operation mode: DC I, II segment operation.

4. Troubleshooting

4.1. Oil chromatography test
After the reactor exits the operation, the oil chromatographic data is analyzed from three samples of the upper and lower oil sample valves of the reactor, as shown in Table 1.

Table 1. Chromatographic analysis of upper and lower oil samples of reactor

| Analysis time | H2 | CH4 | C2H6 | C3H8 | C2H2 | Total hydrocarbons | CO | CO2 | Oil temperature |
|---------------|----|-----|------|------|------|-------------------|----|-----|-----------------|
| 2018.1.28     | 55.9 | 32.6 | 9.3 | 8.6 | 18.37 | 68.87 | 858.4 | 3608.7 | 25.0 |
| 2018.1.28     | 68.2 | 33.0 | 9.2 | 9.2 | 23.52 | 74.92 | 843.0 | 3534.3 | 26.0 |
| 2018.1.28     | 62.8 | 35.5 | 4.8 | 13.0 | 22.02 | 75.33 | 646.8 | 3135.0 | 26.0 |
| 2018.1.28     | 62.9 | 36.9 | 5.3 | 13.6 | 20.85 | 76.66 | 762.9 | 3488.1 | 26.0 |
| 2018.1.28     | 62.0 | 26.8 | 9.0 | 9.3 | 24.90 | 69.90 | 662.4 | 3193.2 | 26.0 |
| 2018.1.28     | 52.9 | 27.6 | 9.3 | 8.9 | 20.80 | 66.60 | 689.9 | 3297.0 | 26.0 |

According to chromatographic data analysis and three-ratio calculation, the fault type is low-energy discharge fault.

4.2. On-site inspection
After the XX substation a phase high resistance failure, the company immediately organized personnel to rush to the scene and actively communicated with the user. After checking the box at the site, it was found that there were discharge marks on the right side of the high-voltage lead wire. As shown in 2, the site cannot be repaired. After negotiation between the two parties, the reactor was returned to the factory for repair.
4.3. Disintegration check

4.3.1. Return to the factory preliminary hood inspection. On March 13, 2018, the phase reactor was visually inspected and no abnormalities were found. After the preliminary lifting hood inspection, the results were as follows: 1) the lid was lifted, and the top and bottom of the inspector were intact. The body is positioned without displacement. 2) Lift the body and check that there is no abnormality at the bottom of the box, as shown in Figure 3.

3) Check the fuel tank wall, a magnetic shield surface on the neutral side box wall has black marks as shown in Figure 4, the corresponding surface covered the inside of the insulating board also found black marks as shown in Figure 5.
4) On the right side facing the high-voltage lead wire, there are dendritic discharge traces on the cardboard screen of the body as shown in Fig. 6. The specific position is about 650mm from the center of the high-voltage lead in the horizontal direction, and 740mm from the uppermost layer of the lower layer of the coil in the vertical direction. About 150mm in diameter.

![Figure 6. The right side of the insulation board and discharge marks](image)

4.3.2. Disintegration check. On March 19, 2018, the reactor was dried and treated, and the inspection results were as follows: 1) Check the contact surface of the upper plate and the bottom plate of the iron core without any abnormality, the upper plate and the lower plate of the iron core. The bolts at the joints with the clamps are not loose and the connection is reliable. 2) No abnormalities were observed in the root of the outlet of the high-voltage lead and the neutral lead, the surface of the lead, and the joint between the lead and the sleeve. 3) Measure the insulation resistance of the iron core and the clamp, and the insulation resistance of the iron yoke shield to the iron core and the clamp member, and the result is normal. 4) Insulation resistance measurement results, the core is 20GΩ to the ground, the clamp is 20GΩ to the ground, and the core is 10GΩ. 5) The results of the insulation resistance measurement of the iron yoke shield on the iron core and the clamp are shown in Table 2:

| Serial number | Measurement item                  | Insulation resistance |
|---------------|-----------------------------------|-----------------------|
| 1             | Left side yoke shield             | 20GΩ                  |
| 2             | Right side yoke shield            | 20GΩ                  |
| 3             | Iron yoke shield on the left       | 20GΩ                  |
| 4             | Iron yoke shield on the right      | 20GΩ                  |
| 5             | Left lower iron yoke shield       | 20GΩ                  |
| 6             | Right lower iron yoke shield      | 20GΩ                  |
| 7             | Grounding screen to iron core     | 20GΩ                  |

From March 20th to March 23rd, 2018, pull out the upper iron yoke to hang the coil as shown in Figure 7. Check the contents and results: 1) Remove the lead and its bracket, lift the iron yoke, lift the coil, check the upper The iron yoke shield, the lower insulation board of the body, the backing plate, the support block and the surface of the iron core, no abnormalities were found.
2) The right side yoke insulating baffle facing the high voltage side was removed, and the surface of the lower iron yoke shield paperboard under the yoke insulating baffle was found to have discharge traces as shown in Figs. 8 and 9. The discharge trace was also found at the lower end of the corresponding yoke insulating baffle.

3) Remove the side yoke insulation baffle facing the left side of the high voltage side, check the iron core bamboo grounding screen, and no abnormalities are found as shown in Figure 10.

4) The outer surface of the outer surface of the outer screen (near 750kV lead outlet side) was found on the surface of the outermost screen board. The isolated dendritic discharge trace was found in Figure
4.3.3. Test result. After the phase is high-resistance, the body is inspected and the inspection results are as follows: 1) On the right side facing the high-voltage lead, the outer surface of the outermost board of the body screen (near 750kV lead outlet side) is found to be isolated. Traces of dendritic discharge (about 150 mm in diameter). 2) A strip black mark (located at the contact with the yoke insulating baffle) is found on the shield surface of the lower yoke facing the high pressure side, and there is a trace of about 25 mm long, 2 mm wide, and dark brown ablation near the high voltage lead side. The trace develops in the direction of the two paths. One path is downward, and the two cardboards of the lower iron yoke are broken down. After opening the iron yoke shield, it is found that there is a point penetrating through the two layers of cardboard, and there is a corresponding discharge point on the aluminum foil. The yoke shield finds a plurality of discharge black spots on the surface of the first layer and the second layer of cardboard; at the same time, the trace develops upward along the yoke insulating baffle at the corresponding position, and the surface of the second layer of the yoke insulating baffle is climbed upward. Trace. At the same time, the core, the lead wire and the coil were inspected, and no abnormality was found; no abnormalities were found on the external parts such as the fuel tank.

5. Calculation check

5.1. The main technical parameters
Sample model: BKD-100000/750
Rated Capacity: 100Mvar
Rated voltage: 8000/ √3
Rated current: 216.5A
Rated impedance: 2133.3Ω
Insulation level:

| Table 3. Reactor insulation level table |
|----------------------------------------|
| Lightning impulse withstand voltage    | Operating impulse withstand voltage(kV) | Short time power frequency withstand voltage(kV) |
| Full wave(kV) | Chopping(kV) |                                   |                                           |
| High pressure side | 2100 | 2250 | 1550 | 900 |
| Neutral side     | 480   | -    | -    | 200 |

5.2. Internal insulation margin simulation calculation
The professional program is used to analyze and calculate the electric field of the coil under the power frequency withstand voltage, and the insulation safety margin meets the requirements. The internal electric field strength calculation result of the body is shown in Figure 12:
Due to the structure of the reactor, the field strengths of different parts are generally different, so the safety margins of different parts are also different. According to the product design requirements, the safety margin of the oil gap is usually greater than 1, which can meet the requirements. It can be seen from the above simulation results that the insulation design safety margin of the body screen, the upper iron yoke shield and the lower iron yoke shield meets the requirements.

6. Cause analysis

According to the disintegration situation, the initial discharge site should be located at the lower yoke shield on the right side facing the high pressure side, and the discharge develops downward through the lower iron yoke shield to shield the first layer and the second layer of cardboard to reach the upper surface of the iron yoke shield aluminium foil. The side yoke insulation baffle climbs to the fifth block. Schematic diagram of discharge position and discharge path:

On the right side facing the high-voltage lead, the isolated dendritic discharge of about 150 mm in diameter found on the body board screen is due to the secondary discharge caused by the gas rise caused by the underlying yoke shield discharge. The discharge here is limited to the outer surface of the outermost board of the screen and does not develop inward. The discharge at the yoke shield is the starting point of the fault. The cause of the fault is partial discharge due to impurities or foreign matter in the yoke shield. Combined with the historical operation and chromatographic data of the product, the disintegration inspection of the product has completely found the problem of failure. The failure of the product is an accidental failure caused by impurities or foreign matter, and the product coil is not involved.

7. Repair plan

According to the disintegration inspection, the high-resistance repair scheme of the phase is as follows: 1) thoroughly clean the surface of the iron core of the product and the strap, and wipe the surface of the yoke with alcohol. 2) Reinforce the coil surface insulation paper and re-process the screen board on the coil surface. 3) Rework the body insulation, including the body yoke insulation baffle, the yoke shield, the upper yoke shield and the lower yoke shield, and reassemble according to the process requirements.

| LINE | Emin kV/mm | Emax kV/mm | Emean kV/mm | Emean(all) kV/mm | Safety |
|------|------------|------------|-------------|-----------------|--------|
| 1    | 2.327      | 2.328      | 2.328       | 8.456           | 3.633  |
| 2    | 2.327      | 2.328      | 2.327       | 8.456           | 3.633  |
| 3    | 2.326      | 2.327      | 2.327       | 8.456           | 3.634  |
| 4    | 2.326      | 2.327      | 2.327       | 8.456           | 3.635  |
| 5    | 2.325      | 2.326      | 2.326       | 8.456           | 3.636  |

Figure 12. Internal electric field strength of the body

Table 4. The safety margin of Oil gap
4) Re-machining several surrounding screens on the outside of the coil, the upper and lower end rings of the coil, the spacers and other insulating parts, the coil tray and the coil inlet corner ring are inspected and reused, and the coil is reassembled according to the process requirements. 5) Thoroughly clean the external components such as high oil tank, measuring and loading, oil storage cabinet, radiator, etc., focus on cleaning the black marks on the magnetic shield of the fuel tank, and replace the covered cardboard on the black magnetic shield. 6) After the reactor is restored, dry, static and test according to the technical requirements of the manufacturer's products.

References
[1] GAO Xiao-dong, QU Wen-tao, CHEN Ren-gang. Fault Analysis and Preventive on 35kV Air-core Dry-type Reactor [J]. Power Capacitor & Reactive Power Compensation, 2015, 36: 85 - 88.
[2] ZHENG Tao, ZHAO Yan-jie, JIN Ying. Fault Analysis and Protection Scheme of Control Windings in Magnetically Controlled Shunt Reactor [J]. Automation of Electric Power Systems, 2014, 35 (10).
[3] WANG Gui-shan, LI Ying-hong, YANG Sheng-jie, LIU Jin. Failure Analysis and Preventive Measures to DRY-type Air-core Reactor [J]. Power Capacitor and Reactive Power Compensation, 2015, 36 (6): 82 – 85.
[4] WANG Hua-xi, GE Shao-jie, DONG Wan-guang, HOU Xian-fa. Fault Analysis of 35kV Dry-type Air-core reactor [J], Power Capacitor and Reactive Power Compensation, 2014, 35 (5): 92 - 95.
[5] GB/T 11024.3-2001 Shunt capacitors for a.c.power systems having a rated voltage above 1 kV Part 3: Protection of shunt capacitors and shunt capacitor banks [S].
[6] GB/T 10228-2008 Specification and technical requirements for dry-type power transformers [S].
[7] XU Linfeng. Fault analysis of dry-type air-core series reactor [J]. Power Capacitor & Reactive Power Compensation, 2008, 29 (2): 50 - 54.
[8] CHEN Zhizhao. Fault analysis and reply measure for10 kV shunt capacitor bank[J]. Guangdong Power Transmission Technology, 2008 (1): 26 - 29.
[9] ZHANG Zhongxian, WANG Weibin, HUANG Dongsheng. Cause analysis on two accidents caused by shunt reactors with dry type air core [J]. Northeast Electric Power Technology, 2006, 27 (11): 17 - 19.
[10] LIU Yuan, DONG Ming, WU Xuezhou, et al. Simulation analysis on anti -seismic characteristics of the 66 kV dry type hollow shunt reactor [J]. Power System and Clean Energy, 2014, 30 (2): 1 - 6.
[11] LEI Yuanyuan, ZHAO Xianping. Parameters selection and arrangement of smoothing reactors for ±800 kV Yunnan-Guangzhou UHVDC transmission project [J]. High Voltage Apparatus, 2012, 48 (6): 75 - 78.
[12] WU Zhao, ZHAO Qingbin. Test study on shunt reactor switching for high voltage AC circuit breaker [J]. High Voltage Apparatus, 2012, 48 (7): 45 - 49.
[13] MIAO Junjie, JIANG Qingli. Fault analysis of a 35 kV dry-type reactor in 500 kV substation [J]. Power Capacitor & Reactive Power Compensation, 2012, 33 (2): 65 - 69.