Failure Analysis of 500kV Gapless MOA

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Abstract. This paper analyzes the cause of a 500kV gapless MOA fault in a substation. The appearance inspection and disassembly analysis of the arrester are carried out. Combined with the protection action, the fault cause of the arrester is analyzed. It is found that the fault is caused by the side flashover failure of the local resistor piece of the line arrester due to the steepness of the lightning invasion wave is large. When the line is reclosed, the lower section bears the over-voltage, resulting in the damage of some resistors, and then causes the pressure release. Based on the analysis the paper puts forward some corresponding operation and maintenance measures.

1. Introduction

With its advantages of continuous and flat volt ampere characteristics, fast response to over-voltage, simple structure, good protection performance, and convenient installation and operation detection, gapless metal oxide arrester is widely used in substation, effectively ensuring the safe and stable operation of equipment in the substation [1-3]. However, due to the absence of series gap, the resistor piece should not only bear lightning over-voltage, but also power frequency over-voltage and resonance over-voltage. Therefore, there are problems of deterioration and thermal stability under the effect of these kinds of over-voltage [4-5]. In recent years, failure, explosion and other accidents of lightning arrester have occurred from time to time, which seriously affects the safe and stable operation of the electric power system [6-10].

This paper analyzes the cause of a 500kV gapless metal oxide arrester fault, and puts forward operation and maintenance measures to improve the safe operation level of arrester in substation [6].

2. Fault overview

At 03:48 on June 23, 2019, phase B of circuit breakers on both sides of 500kV Line A and Line B was tripped and reclosed. The substations on both sides of Line A and Line B were in thunderstorm weather. After the on-site inspection, as shown in Figure 1, it was found that the explosion-proof membrane at the interface of three porcelain pillars of phase B lightning arrester in 500 kV substation B acted black, and the leakage current monitor was burned, as shown in Figure 1. The counter of B-phase arrester of substation A acted twice, and the appearance of arrester was normal. The leakage current monitor of B-phase arrester in substation B couldn’t record the action times due to the damage. After tripping, the infrared temperature measureent was carried out on the faulty B-phase arrester of substation B. It was found that the temperature of phase B was 6.8°C higher than that of phase A and C, as shown in Figure 2. The relevant protection of Line A and Line B was checked to work normal, and no abnormality was found in other equipment.
Figure 1: Photo of faulty B-phase arrester.

(a) Explosion proof membrane. (b) The leakage current action monitor was burned.

Figure 2: Temperature measurement photo of arrester

(a) Temperature photo of B-phase arrester. (b) Temperature photo of A and C-phase arrester.

3. Inspection and analysis of arrester disassembly

3.1. Historical operation of arrester
The faulty B-phase arrester is a gapless metal zinc oxide arrester with the model of Y20W-444/1106W1, which was produced in November 2016 and put into operation on June 30, 2017 [11].

Since it was put into operation, the relevant documents of the factory are complete, all the factory test report, on-site handover test and annual preventive test are qualified. The annual AC leakage current live test under operating voltage conducted before thunderstorm season was qualified. The comprehensive analysis and comparison of various data of the test items showed that the test data was qualified.

3.2. Inspection and analysis of arrester disassembly

3.2.1. The appearance of the arrester was inspected and the DC parameters of the three-section components were tested. The upper and lower explosion-proof plates of the three components were cracked, the protective plates were warped and the inner surface was blackened. The pressure release action occurred in all three-section components. The appearance of the porcelain bushing was normal. There were discharge traces in the large ring of the grading ring. The DC reference voltage of the three-section components was close to zero.

3.2.2. There were no abnormalities in the upper and middle section sealing cover plates, pressing plates and sealing rings of the arrester; there were penetrating ablation marks from top to bottom on the inner wall of the upper section porcelain bushing; there were local arc ablation marks on the inner wall of the middle section porcelain bushing; there were obvious creepage marks on the outer surface of the core from top to bottom, and the external surface flashover traces of different degrees were found on the resistor piece by piece.

3.2.3. The sealing cover plate, pressing plate and sealing ring of the lower section of the arrester were normal; there were local ablation marks on the inner wall of the porcelain bushing; there are obvious creepage marks from top to bottom on the outer surface of the core. The external surface flashover traces of different degrees were found on the resistance pieces. Among them, the bottom five pieces of
resistors had been damaged, and the insulation rod had ablation marks at corresponding positions, as shown in Figure. 3.

(a) Sealing cover plate, pressing plate, sealing ring and insulating rod.

(b) The lower section core. (c) The inside walls of the lower porcelain sleeve.

(d) The lower section resistors.

Figure 3. Photo of B-phase arrester disassembly

3.2.4. The voltage recovery characteristics of the resistor were tested. Three pieces of upper, middle and lower section resistors without damage were selected and wiped with alcohol & cotton cloth for DC reference voltage test. The test results were close to zero. After removing the organic glaze on the surface of 9 resistors under 400℃, DC reference voltage test was carried out, and the voltage recovery occurred in all resistors; which verified the integrity of the resistor body and indicated that the fault was caused by side flashover.

4. Analysis of lightning and protection

The protection action information of the substations on both sides of 500kV Line A and B was obtained respectively. The fault occurred at 03:48:58:491ms. There was non sine wave mutation in B-phase current and voltage of 500kV Line A and Line B, and instantaneous non power frequency differential current occurred. The differential protection action on both sides of the line correctly tripped the B-phase circuit breaker on both sides of the line. The fault recording distance was 78.2km away from substation A and 32km away from substation B. According to the lightning location system, there were four lightning strikes near Tower 129 and Tower 130 within 3 minutes before and after the fault time, among them, the currents of two lightning stokes were about - 56kA, - 38kA respectively. The distance between the lightning point and the substation was consistent with the measured distance of the fault recorder.

At 03:48:59:446ms, that was, 955ms after fault, reclosing action occurred, reclosing at fault three-phase trip. Checked the protection action waveform, the circuit breaker of substation A reclosed
16 ms earlier than that of substation B, and the switching over-voltage appeared at the moment of reclosing, with the peak value of 832.9. There were obvious large sine wave fault current and zero sequence current in B phase of two stations. The differential protection and reclosing acceleration protection of the two stations acted correctly to make the three-phase circuit breakers on both sides of the lines tripped. The fault recording distance was 110 km away from substation A and 0 km away from substation B. The fault location results were consistent with the fault arrester.

Based on the lightning location system and protection action, it is considered that phase B of 500kV Line A and Line B suffers from lightning stroke, which causes single-phase fault. The protection acts correctly to make phase B tripped. When the time of reclosing is up, the circuit breaker at substation A is closed 16 ms earlier than that at substation B. the B-phase arrester in substation B releases pressure under the combined action of atmospheric over-voltage, switching over-voltage and power frequency over-voltage, which finally leads in reclosing and the fault of triple trip.

5. Analysis of Failure Causes
Based on the disassembly inspection, lightning record and protection action, the causes of failure happened on B-phase arrester are analyzed as follows:

The B-phase arrester of 500kV substation B continuously withstood two steep lightning intrusion waves in a short period of time. The line protection acted correctly, the B-phase circuit breakers on both sides of the line were tripped, and the line reclosing acted. The circuit breaker at the side of substation A acted first, and the line was standing in no load condition in a long-distance. At this time, the B-phase arrester of substation B beared atmospheric overvoltage, switching overvoltage and power frequency overvoltage at a short time. Due to the common impact of voltage, the energy absorbed by the arrester was far greater than its endurance capacity, resulting in the side flashover failure of the local resistor piece of the line arrester and the damage of the lower part of the resistor plate, so as to cause the occurrence of three sections of pressure release action [6] and damage of the leakage current monitor.

6. Countermeasures

6.1. Strengthen the selection of equipment. According to the disassembly, the arrester is impacted by multiple overvoltages such as lightning overvoltage, switching overvoltage and power frequency overvoltage in a short period of time, and the release current of arrester exceeds its bearing capacity. For the arrester installed in the lightning area, those with greater flow energy and stronger endurance should be selected, which should have sufficient high current withstand capacity [7].

6.2. Check the energy absorption capacity. The energy absorption capacity of lightning arrester includes the operation impulse energy absorption capacity and the lightning impulse energy absorption capacity. The energy absorption capacity under operation shock mainly adopts long duration current impulse for assessment. For different levels of arrester, it can be evaluated by line discharge withstand capacity test or square wave impulse current tolerance capacity. The energy absorption capacity under lightning impulse is mainly assessed by high current impulse. The resistance piece of gapless arrester shall be subjected to high current impulse withstand test. Under such high current impulse, the resistor shall not be damaged by breakdown or flashover [12].

6.3. Strengthen the live test. The live test of AC leakage current under operating voltage can timely find out that the internal insulation condition of oxide arrester is poor, the valve piece is aged, damp, and the internal insulation parts are damaged, which is an important means to judge the state of arrester. In accordance with the “Code of Maintenance Test for Power Equipment” (Q/CSG1 206007-2017), the lightning arrester of 35kV and above should be measured once within half a year after operation, once every year before thunderstorm season after one year of operation, or when it is suspected that there are defects. When the resistive current increases by 50%, the cause should be
analyzed, the monitoring should be strengthened, and the detection period should be appropriately shortened; when the resistive current is doubled, it should be inspected after the power is cut off [13].

6.4. Strengthen the operation maintenance. The indicator and leakage current value of arrester discharge counter shall be recorded every month and after thunderstorm or accident. Then, compared with the continuous current value of other arresters under the same operation conditions, there shall be no obvious difference. Infrared thermal detection shall be conducted once a month, and the arrester body and electrical connection parts shall be detected with infrared thermal imager, and no abnormal temperature rise, temperature difference and/or relative temperature difference shall be shown in the infrared thermal image. which shall be implemented according to “DL/T664-2016 Application Rules for the Infrared Diagnosis of Electrical Equipment”[14].

7. CONCLUSION
In this paper, a 500kV gapless MOA fault is analyzed, and the cause of the fault is found out through on-site inspection and disassembly analysis. The damage of arrester is caused by two lightning invasion waves with large steepness in a short period of time, and the common impact of atmospheric overvoltage, switching overvoltage and power frequency overvoltage. Based on the analysis the paper puts forward some corresponding countermeasures, which can provide reference for preventing and dealing with similar faults of arrester, and help to ensure the safe and stable operation of power system.

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