Cause analysis and preventive measures of 500kV shunt reactor bushing failure

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Abstract. In response to a recent 500kV line shunt reactor high-voltage bushing failure event in a station, this article examines and analyzes the objects and protection actions after the casing is disassembled. It was found that the cause of the casing failure was caused by the arc igniting the insulating oil in the casing after the main insulation of the casing was discharged. Finally, corresponding preventive measures are proposed from the perspective of on-site operation and maintenance.

1. Introduction

The high-voltage bushing is an important part of the main equipment such as transformers and shunt reactors. Its function is to lead the high-voltage lead from the cabinet of the equipment, and at the same time, it can insulate the shell from the high-voltage lead\cite{1-5}. At present, transformer bushings with voltage levels of 110 kV and above generally use oil-paper capacitive structures. The oil-paper capacitive bushings are rolled by the principle of capacitive voltage divider. The transformer windings are led to the outside and connected to the power grid with lead connectors. The capacitor core composed of conductive aluminum foil is used as the internal insulation structure, the porcelain sleeve is used as the external insulation, and qualified transformer oil or SF6 is injected in the middle to play the role of insulation and heat dissipation\cite{6-9}. According to statistics, accidents caused by oil-paper capacitive bushing failures account for about 1/6 of the country's total transformer accidents\cite{10-12}.

In response to a 500kV line shunt reactor high-voltage bushing failure event that occurred in a station recently, this article examines and analyzes the objects and protection actions after the bushing is disintegrated, and finds that the cause of the bushing failure is after the main insulation breakdown of the bushing. The arc ignites the insulating oil in the casing, and corresponding preventive measures are proposed from the perspective of on-site operation and maintenance.

2. Failure overview

At 20:58 on July 4, 2020, main-one integrated auxiliary A protection action and main-two integrated auxiliary B protection action of a 500kV line appeared. The 5021 and 5022 three-phase circuit breaker tripped. 5021 High voltage shunt reactor non-electric quantity protection heavy gas tripped. High oil temperature was warning (protection setting does not use high oil temperature trip function). High winding temperature was warning (protection setting does not turn on high winding temperature trip). Light gas was warning. Abnormal oil level was warning. The attendant saw a fire in the main control room of a 500kV line in the equipment area. Inspection after the fire found that the high-voltage and neutral bushings of the reactor had been burned, as shown in Figure 1.
Figure 1. Overall situation of high-voltage casing after burning

The overfire area of the outer surface of the fuel tank is large, but the fuel tank has no cracks or deformation as a whole; There are traces of fire on the side of the radiator close to the fuel tank; the oil conservator has a greater degree of overall fire. The high-voltage bushing is the most damaged, the porcelain bushing has been completely broken, and the debris is scattered around. The head of the casing has been partially melted, and the overhead line connected to the casing has been disconnected. The metal parts at the connection between the casing ceramic sleeve and the flange have exploded and divided into several small pieces. The casing capacitor core is exposed, and some of it has been burned. The end of the tube extends into the fuel tank and cannot be viewed. The overall surface of the fuel tank is obviously overfired. The top and wall surfaces of the fuel tank have burnt black. The seals at the upper and lower fuel tanks fail under high temperature, and there is oil leakage along the joints of the upper and lower fuel tanks. The situation is shown in Figure 2.

Figure 2. High resistance fuel tank situation

3. Failure cause analysis

3.1. Historical operation of high-voltage shunt reactor and its bushing

The high-resistance model of the faulty casing is BKD-40000/500. The high voltage casing code is casing code OT813K. Since it was put into operation, the relevant materials of the factory are complete, and the factory test report, on-site handover test and annual preventive test are all qualified. During operation, the high-voltage reactor body and casing shall be inspected once a week, and the infrared temperature measurement of the high-resistance casing, body and wire connection shall be carried out once a month. No abnormality is found, and there is no abnormality in the infrared inspection oil surface; Multi-dimensional analysis of high resistance oil temperature, bypass temperature, oil temperature, and oil level was carried out every month, and no abnormality was found.
3.2. Analysis of protection action

The analysis of the protection action of the high-voltage reactor during the fault is as follows. High voltage reactor differential protection takes high voltage side and low voltage side bushing current transformer. The differential current of phase B is 0 A. The fault current presents the characteristics of through current, explaining that the point of failure is outside the zone. Therefore, the two sets of high-resistance electric quantity protection do not operate. At 16ms, the non-electrical protection pressure release action of the high-voltage reactor generates an alarm. In 32ms Heavy Gas jump ABC three-phase, and it send a long jump command to the main one integrated auxiliary A, main two integrated auxiliary B protection to jump the opposite breaker. In the whole process, high voltage reactor protection works correctly.

3.3. The situation of previous test and maintenance

According to the regulations, the high resistance has been periodically pre-tested and checked, and the test data are all qualified. The results of the last three preventive tests and insulating oil chromatographic analysis are as follows:

1) In December 2013, December 2015, May 2018, the DC resistance of the winding, the insulation resistance of the iron core and clamps, the insulation resistance and absorption ratio of the winding, the bushing insulation resistance, the bushing dielectric loss and the capacitance were tested respectively. Test data meet "Q/CSG 114 002-2011"Preventive Test Regulations for Power Equipment", No abnormality was found and the test passed.

2) From 2018 to 2019, 11 times of oil dissolved gas analysis and 3 times of oil quality analysis were carried out (Breakdown voltage, water content, gas content, dielectric loss). Except for H$_2$ super attention value, the rest of the test data meets Q/CSG1206007-2017 Requirements of "Power Equipment Maintenance Test Regulations", Its H$_2$ annual test results from 2018 to 2019 showed no significant growth in.

3.4. Return back to the factory for anatomy

Disassemble the reactor, the situation is as follows:

1) The high-voltage point iron cores, clamps, and coils are relatively intact, causing serious pollution.

2) The capacitor core of the high-voltage bushing is seriously damaged. There are arc ablation marks at the side distance of 570mm from the bottom of the coiled pipe oil. The flange CT tube is cracked from top to bottom about 600mm long, and there are many arc ablation marks on the inner side of the lower edge. The air side flange is broken, and there are many arc ablation marks on the inside of the flange fragments, as shown in Figure 3 and Figure 4.

Check the inner wall of the porcelain sleeve fragments and no obvious creepage traces are found. There are wrinkles in the aluminum foil inside the capacitor core near the coiled tube, as shown in Figure 5.
3.5. Failure cause analysis
According to the analysis of the protection action, the high-resistance protection is an out-of-zone fault, and the fault is located in the line protection zone. The fault location is in the substation. Combined with the on-site appearance inspection, there are 3 obvious discharge marks on the flange of the casing riser, so the fault is The starting point should be at the upper part of the middle flange of the casing. The casing explosion and fire are caused by the main insulation breakdown discharge and the arc ignites the insulating oil in the casing. The main reasons are as follows:

1) When the fault occurs, the 500kV line where the high-voltage reactor is located is not in operation, the weather is cloudy, check the lightning positioning system, there is no lightning record in the surrounding area, the line and the high-resistance arrester are not operating, and the atmospheric overvoltage and operating overvoltage can be ruled out. Regardless of the possibility of failure, the failure should occur under the operating voltage.

2) The casing end screen grounding device has no discharge traces, and the possibility of a suspension potential caused by a poor end screen grounding can be investigated.

3) The casing riser seat (ground potential) is where the distance between the live conductor and the ground potential is the smallest, where the electric field strength is the largest. When the insulation strength of the casing capacitive screen drops to the extent that it cannot withstand the working field strength, the casing conductive tube will affect the riser seat Discharge, forming a penetrating discharge channel, a fault generates a strong short-circuit current, leaving burn marks at the position of the raised seat corresponding to the short circuit. Under the action of a large current, the insulating oil in the bushing will suddenly vaporize and expand, causing the bushing to explode.

4) The arc ablation trace on the coiled tube is the starting point of discharge, and the discharge path develops from the inside to the outside, which leads to the breakdown of the CT tube and the air side flange. The cause of the failure may be aluminum foil folds or foreign matter in the insulating paper, which leads to the capacitive screen Local electric field distortion occurs, and partial discharge occurs under the long-term action of the operating voltage, which gradually develops from the inside to the outside to an insulation breakdown.

4. Precautions
1) when the main transformers and high-resistance equipment of various substations are tested and other work involving the end screen of the casing, the grounding condition of the end screen should be checked after the last screen is disassembled, and the casing should be ensured when recovering. The last screen is well grounded.

2) Strictly follow the "Power Equipment Maintenance Test Regulations QCSG1206007-2017"Carry out the verification and analysis of capacitive casing test data, and check the casing test data item by item to ensure that the data is accurate. Retest the casing with abnormal data. Before the power failure retest is completed, the infrared temperature measurement cycle of the casing body should be
shortened. Not less than once every two weeks, strengthen the analysis of the temperature difference profile of the casing surface.

3) For casings that still have abnormalities after retesting, further evaluation should be carried out. When the increase in dielectric loss exceeds 30% or the capacitance changes significantly, oil chromatographic analysis should be carried out for oil-immersed casing, and detailed analysis should be carried out for dry casing. If it is still unqualified after the evaluation, it should be replaced and disintegrated analysis.

4) The casing oil sampling should be completed under the guidance of the casing manufacturer. During the process, the operation should be carried out in strict accordance with the standard requirements, the relevant seals should be replaced, and the risk of casing moisture should be strictly controlled.

5) Continue to promote the condition assessment of the old casing for more than 15 years, carry out the dielectric spectrum test in conjunction with the power outage, and conduct the oil chromatography spot check on some casings.

5. Conclusion
In response to a 500kV line shunt reactor high-voltage bushing failure event that occurred in a station recently, this article examines and analyzes the objects and protection actions after the bushing is dismantled, and puts forward specific preventive measures after analyzing the cause of the failure. Equipment defects provide a feasible judgment and test method, which helps to ensure the safe and stable operation of the power system.

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References
[1] ZHANG, J.L., YAN, J., GUO, L. (2012) The case study of abnormal dielectric loss data of capacitive potential transformer bushings. J. Shanxi Electric Power.,2:20222.
[2] CHEN, A.M., YANG, Y.,HUANG, W.L.,et al. (2013) Di-electric loss test and analysis of transformer oil paper capacitive bushing. J. Insulating Materials.,46:80-82.
[3] WANG, J.D., DONG, W.G., HOU, X.f. (2012) The di-electric loss of 110 kV transformer bushing analysis and processing. J. Transformer., 49:67-68.
[4] LIN, H.,WANG, Y.F. (2008) Analysis on the reason of transformer thimble fault. J. Power System Technology.,32:253-255.
[5] SUN, Y.,ZHU, J.X. (2008) Cause analysis of an explosive accident of converter transformer bushing. J. Southern Power System Technology.,2:82-83.
[6] Liu, Y.P.,LV, F.C.,LI, C.G.,et al. (2004) On-line monitoring transformer’s bushing insulation based on its tap capacitive divider. J. High Voltage Apparatus,40:121-123.
[7] NIE, D.X.,WU, Z.R., LUO, X.Z.,et al. (2010) Analysis on the partial discharge test technology of UHV transformer bushing. J. High Voltage Engineering.,36:1448-1454.
[8] WANG, N.,CHEN, Z.Y.,LV, F.C. (2003) A survey of on-line monitoring and diagnosis for capacitive equipment. J. Power System Technology.,37:72-76.
[9] ZHENG, S.S.,LI, C.R.,HE, M. (2013) A novel method of newton iteration in complex field and lattice search for locating partial discharges in transformers. J. Proceedings of the CSEE.,33:
[10] WANG, Y., SUN, Q., ZHUANG, H.M., et al. (2007) Field tests on the new capacitive high voltage equipment and dielectric loss of the end shield. J. High Voltage Engineering, 33: 183-185.

[11] PAN, G.H., ZHU, H.Y. (2013) Key technologies research for the installation and field test of ±800kV wall bushing. J. High Voltage Apparatus, 49:98-102.

[12] LI, H.L., HAO, Y.L., ZHONG, L., et al. (2011) Investigation on AC flashover of a 550 kV oil impregnated paper transformer bushing. J. High Voltage Apparatus, 47:68-71.