Analysis and treatment of insulation abnormality of a 220kV wall bushing end shield

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Abstract. This work expounds a case of insulation abnormality of a 220kV wall bushing end shield caused by the failure of rubber seal gasket. The mechanism and causes of insulation abnormality were put forward combined with the method of on-site inspection, XRF analysis, infrared spectroscopy (IR) analysis and thermogravimetric analysis. And suggestions for the improvement of sealing performance to prevent this kind of defect and management of operation and maintenance of bushing end shield were proposed.

1. Introduction
Dry type wall bushing is widely used in indoor electrical equipment substation, due to its simple structure, convenient installation with high reliability, low price and less maintenance. And capacitive type was generally adopted in the bushing insulation structure of 110 kV and above, which can ensure uniform radial and axial field strength distribution. The structure of capacitive type is achieved by wrapping many insulating layers on the conductive rod, and many aluminum foils are sandwiched between them according to the characteristics of field strength distribution, so as to form a series of concentric cylindrical capacitors. Among then, the outermost aluminum foil (also called end shield) is led out through a small bushing for measuring the dielectric loss and capacitance of the bushing. The end shield should be reliably grounded during operation. If the bushing end shield is poorly grounded, a high voltage will be formed at the poor grounding, which will cause the bushing end shield to discharge to the grounding and even burst, seriously endangering the safe operation of transformer [1, 2].

This work investigated a 220 kV substation near river where the ambient humidity is higher than 70% all the year round. In the process of a centralized maintenance, it was found through routine tests that the insulation of wall bushing end shield of the 516A phase was 0 MΩ, and the insulation of other B and C phase end shield was normal. To explore the cause of the defect, on-site inspection, XRF
analysis, IR analysis and thermogravimetric analysis were carried out. And relevant preventive measures to provide a reference for operation and maintenance stage was proposed.

2. On-site inspection
By checking the nameplate, this bushing is epoxy resin capacitive wall bushing with model EAA-126/1250-3. The bushing structure mainly includes porcelain bushing, flange and capacitor core, etc. The capacitor core as main insulation is made of insulating paper and aluminum platinum electrode wound on the conductive rod. After vacuum drying and impregnated with epoxy resin, it becomes an insulator with high electrical performance and mechanical strength. The structure of wall bushing end shield can be classified as built-in grounding [3], and its structural principle is shown in Figure 1. Thereinto, the lead wire of the wall bushing end shield is led out through the lead post which is insulated from the ground. The metal ground ring is closely connected with the lead post. During operation, the metal ground ring is connected with the metal flange inside the bushing under the pressure of the spring, so that the bushing end shield can be reliably grounded. The outermost part is protected by a metal cap and sealed against moisture.

![Figure 1. Schematic diagram of wall bushing end shield structure.](image)

The insulation performance test of 516A phase bushing end shield is conducted on site, and the process is shown in Figure 2. The ground ring was pressed down to separate it from the shell of end shield, and then the insulation performance of the lead post detected was 0 MΩ. While, the insulation of Yellow filling adhesive around the bushing end shield lead wire is infinite without any abnormality. In order to further explore the fault location, the body shell of bushing end shield was separated from the metal flange with only connected to the bushing end shield lead wire, as shown in Figure 2. In this case, the insulation resistance of lead post was measured at 1.59 GΩ that is qualified. Yet by putting the body shell of bushing end shield back the insulation resistance of lead post decreased to 0 MΩ. It can be obtained that ground fault occurs in interior of the bushing end shield structure above the lead wire.

![Figure 2. Field insulation test of 516A phase through wall bushing end shield.](image)
In order to observe the internal situation, the outer cover of the bushing end shield was disassembled, as shown in Figure 3. During the process of disassembly, a large number of metal oxide fragments and powder were spilled out. Meanwhile, it can be seen that serious oxidation, corrosion, falling off and damp occur in the shell of bushing end shield. The seal gasket has been deformed and there are a large number of falling debris and powder accumulation on the upper part of the seal gasket. And the bottom of ground ring has turned black. Meanwhile, the insulation resistance of seal gasket was measured at 34 MΩ by the insulation test. The entire bushing end shield was reassembled after the seal gasket was cleaned simply, and the insulation resistance of it rose to 374 MΩ.

According to the above results, it can be seen that the direct cause of the ground fault of the wall bushing end shield of 516A phase is that the internal deactivated seal gasket cannot prevent moisture to penetrate inside. Water vapor enters the shell, resulting in the metal oxidation on the inner wall surface of the shell and then the internal metal powder gradually accumulates, as shown in Figure 4. Thereinto, the red dots represent the metal fragments and powder falling off the inner wall of the end shield, and light green and blue lines respectively represent the seal gaskets of the end shield. Due to the absorption of moisture, the green seal gasket has a lower insulation of 206 MΩ by the test. Furthermore, the deterioration of the sealing performance of the green seal gasket brings about the penetration of moisture. The metal material of shell is damp and oxidized over time to form metal fragments even powder which falls off and accumulates on the blue seal gasket under the gravity factors and the continuous deepening of corrosion and oxidation. As a result, the insulation of the blue seal gasket drops to a very low level of 34 MΩ. The metal debris and powder on the blue seal gasket accumulate to a certain extent, which makes the lead post form a grounding connection on the surface of the white insulating pad at the bottom, and makes the ground ring lose the function of switching grounding, resulting in the wall bushing end shield always in the grounding state.

Through the inspection of the bushing end shield of the interval, for the bushing end shield whose inner wall and spring were seriously rusted or the seal gasket was deformed and cracked the maintenance personnel carried out the following treatment. Remove the metal rust powder, polish and clean the oxidation part, replace the new seal gasket, and reassemble as a whole. After reassembling,
the key parts such as base gap and screw hole were filled with sealant to improve the sealing performance. The insulation of the bushing end shield is recovered from 0 MΩ to infinity and other data are qualified after these treatments. In order to further explore the causes of the seal failure, the relevant experimental research on the seal gaskets was carried out.

3 Test and results

3.1 XRF analysis

The elements of the metal material of the bushing end shield shell is tested by Olympus handheld XRF Analyzer. The material composition data of the shell of bushing end shield is obtained as shown in Table 1.

It can be seen from Table 1 that the composition of aluminum and silicon elements in the shell accounts for more than 90%, which can be preliminarily judged as cast aluminum alloy 4-series. The silicon element in the oxidation corrosion site is higher than the average level, and the distribution of silicon element in the whole material is uneven. With the increase of silicon content, the hardness, strength, and wear resistance of aluminum alloy 4-series will be improved, but its cutting performance will be greatly reduced. The primary silicon of high aluminum silicon alloy is very coarse. If it is directly cast by conventional methods instead of modification and refinement, the qualified rate of products will be greatly reduced.

| Component       | Al   | Si  | P   | Fe  | Mn  | S   | Zn  | Pd  |
|-----------------|------|-----|-----|-----|-----|-----|-----|-----|
| Average value % | 79.68| 10.87| 2.95| 1.95| 1.87| 1.66| 0.68| 0.15|
| Oxidation site %| 80.37| 16.15| 1.49| 0.75| 0.62| 0.47| 0.12| 0.03|

3.2 IR analysis

The IR analysis are conducted on a Bruker sensor Fourier transform decay total reflection infrared spectrometer (ATR sampling system) opus, with a resolution of 4cm⁻¹ and scanning times of 32 times. According to the appearance of the seal gasket, it can be roughly judged as a cork rubber, and the results of IR spectra can be seen that the three seal gaskets used on the bushing end shield are all of the same material, and take the biggest seal gasket (correspond to green seal gasket) as an example as shown in Figure 3(c).

The IR spectra of the seal gasket are shown in Figure 5. The peaks at 2922.54 cm⁻¹ and 2852.37 cm⁻¹ correspond to the asymmetric and symmetric vibration of saturated hydrocarbon methylene respectively. And the peaks at 1483.30 cm⁻¹ and 1421.67 cm⁻¹ were assigned to the in-plane deformation vibration of saturated hydrocarbon methylene. The peak observed at 968.49 cm⁻¹ was attributed to the external bending vibration of C-H in trans 1, 4 structure C=CH in the molecular structure of Styrene butadiene rubber (SBR), the peak at 1592.36 cm⁻¹ corresponds to the C=C expansion vibration on benzene ring in polystyrene, and the peak at 756.94 cm⁻¹ was assigned to the external bending vibration of the single substituted benzene ring C-H [4]. Broad peaks observed at 3440 cm⁻¹ corresponds to the symmetric expansion vibration zone of -OH, and the peak of 1737.76 cm⁻¹ and 1240.30 cm⁻¹ were indicative of ester bond, which confirmed cork particles added in the seal gasket. It can be judged that the seal gasket is SBR with cork particles added [5]. The drawback of SBR is its high gas permeability and its low ozone resistance which are undesirable in preventing moisture for a long time [6].
Figure 5. The IR spectrum of seal gasket.

3.3 Thermogravimetry
The thermal stability of the seal gaskets are tested by thermal gravimetric (TG) analysis. The thermal gravimetric analysis of seal gasket material was carried out by Mettler Toledo TGA2. The samples (about 5-10 mg) were heated from 30 to 800 °C at a heating rate of 20 °C/min under argon steam (flowing at 50ml/min).

The TG and DTG curves of seal gasket (take the biggest seal gasket as an example) is shown in Figure 6. It can be seen that the small weight loss (about 3.6%) occurred before 200 °C in the first stage, which was mainly caused by the loss of water and impurities in the seal gasket. The second stage of thermal decomposition of seal gasket occurring between 200-410 °C accompanied by a weight loss of 36.2% is connected with the decomposition of the cellulose in cork. The third stage occurred at more than 410 °C, which was mainly due to the breaking of the C-C bond in the aromatic ring and molecular chain of sample. About 35.3% of total mass remain at the end of the thermal decomposition, which was the additive component and carbon residue in rubber [7, 8]. The characteristics of thermal decomposition support that IR conclusion.

Figure 6. The TG and DTG curves of seal gasket.
4 Conclusion and suggestion
The poor grounding of the wall bushing end shield is usually the key cause of the bushing fault. And the seal gasket plays a key role in preventing moisture from entering bushing end shield. Moisture entering into the bushing end shield for a long time will cause internal metal corrosion, lead to abnormal insulation, spring failure and other problems, which could severely harm the stable operation of transformer. For the repair and maintenance of the dry type wall bushing end shield, some suggestions are proposed as follows.

1) The old seals with the problems of elasticity decline and appearance serious deformation should be replaced in the process of maintenance. And the water impermeability and aging resistance of the seal gasket used in this kind of end screen should be considered first, such as the nitrile rubber (NBR), EPDM and so on. Then the key parts such as the gap of the end shield base and the screw hole can be filled with sealant to improve the overall tightness during the assembly.

2) Enhance the daily operation and maintenance management of bushing end shield. The operation personnel of substation should pay attention to whether there is abnormal discharge noise at the bushing end shield during daily inspection. In the routine test work of equipment maintenance, maintenance personnel should pay attention to check whether there are traces of suspended discharge in the bushing end shield cover, the elasticity of spring device, the appearance and elasticity of seal gasket. And when the bushing end shield is restored to the grounding state, the resistance value of the bushing end shield to the equipment shell should be measured by a multimeter.

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