Analysis of the Cause of Leakage Oil Defect in a Voltage-Dividing Capacitor of a 500kV Porcelain Circuit Breaker

Xuefei Yang1*, Hongkun Li1 and Chunhong Wu1

1 China Southern Power Grid EHV Power Transmission Company Liuzhou Bureau, Liuzhou, Guangxi, China
* e-mail: yangxuefei@ehv.csg.cn

Abstract. In recent years, with the development and construction of the power grid system, the porcelain column circuit breaker has been popularized and applied in the 500kV substation. However, in the actual operation and maintenance process, the leakage of oil has been found in the grading capacitor. The disassemble of an oil leakage grading capacitor of a 500kV porcelain column circuit breaker is analyzed in this paper. Through carrying out the sealing test; the insulation performance test; salt spray test and simulation test. At the same time, by comparing the sealing ring and cover plate material; calculating the potential difference of the cover plate and researching electrochemical corrosion factors. We can come to an conclusion that the cause of a suspected the grading capacitor oil leakage is the oil accumulation and the main reason for the oil leakage problem of the grading capacitor is the electrochemical corrosion phenomenon on the sealing cover plate. Finally, on the basis of the reasons, the relevant rectification measures are put forward.

1. Introduction
Circuit breaker is an indispensable important equipment in power system. Its safe and reliable operation plays an important role in ensuring the stable operation of power system and reliable power supply. With the increasing scale of China's power grid and the continuous improvement of voltage level, 500kV power grid has become the backbone network of provincial companies, and the open type porcelain column circuit breaker has been widely applied in 500kV substation. In order to improve the overall withstand voltage level of porcelain post circuit breaker, voltage equalizing capacitor is widely used as an element to improve the voltage distribution between the fracture surfaces of porcelain post circuit breaker. However, in the actual operation and maintenance process, it is found that there is oil leakage in the equalizing capacitor of the circuit breaker [1-2]. Therefore, it is necessary to test and analyze the oil leakage of the voltage equalizing capacitor of the circuit breaker, find out the causes of the defects and put forward improvement measures.

2. Defect overview and equipment information
In November 2017, there were four oil leakage defects of voltage equalizing capacitor in converter station A. The oil leakage part is the assembly gap between the capacitor bushing flange and the cover plate, as shown in Figure 1. The specific installation position of the leakage equalizing capacitor is shown in Table 1. In November 2018, 23 cases of voltage equalizing capacitor oil leakage were also found in converter station a; in October 2019, one leakage of voltage equalizing capacitor was found in B converter station. According to statistics, 73 sets of 3ap2-fi type porcelain column circuit breakers are used in the
two stations. The rated voltage is 250kV. The grading capacitors are produced in the same batch, and the rated capacitance is 2000pf.

![Figure 1. A leakage oil pressure equalization capacitor](image1)

### Table 1. Leakage oil pressure condenser capacitor installation location

| Time       | Installation position     | Fault phenomenon                                      |
|------------|---------------------------|-------------------------------------------------------|
| 2017.11.17 | A station 554 circuit breaker phase A | A-phase pressure equalizing capacitor ends with oil traces |
| 2017.11.18 | A station 5112 circuit breaker phase A | A-phase pressure equalizing capacitor ends with oil traces |
| 2017.11.26 | A station 5092 circuit breaker A phase | A-phase pressure equalizing capacitor ends with oil traces |
| 2017.11.27 | A station 5063 breaker B phase | B phase pressure equalizing capacitor tip oil leakage |

### 3. Failure analysis

#### 3.1. Sealing test

From January 16 to 17, 2018, a total of 6 voltage-dividing capacitors with oil leakage were selected and sent to Suzhou Electric Appliance Research Institute for sealing test. According to GB/t 4787-2010, the test temperature was 65 °C and the test time was 8h (the temperature maintained for 8h after the temperature reached 65 °C). The test results show that: the oil leakage phenomenon of main seal of equalizing capacitor with individual oil leakage signs is more obvious after sealing test; however, oil leakage phenomenon is not found in equalizing capacitor with some oil leakage signs after sealing test, but there is oil leakage at waterproof glue [3-4]. Oil leakage path of equalizing capacitor is shown in Figure 2. Path 1 Casting gaps for flanges and porcelain pipes (shims → cast cement → waterproof glue): Path 2 Flange seal gap with bottom or cover.

![Figure 2. The path of pressure equalizing capacitance seepage](image2)

The oil leakage parts of some suspected oil leakage samples all appear at the waterproof glue, which shows that the oil leakage is caused by oil accumulation, not the medium leakage in the voltage
equalizing capacitor. The oil source is produced in the "vacuum impregnation process". Due to the difference in the actual amount of oil injected into each product, the phenomenon of oil overflow will occur during the oil injection process. Because there are usually gaps or pores between the layers of the connecting parts in path 1, the oil medium is inhaled or infiltrated from the gasket to form oil accumulation here. After the cover is sealed, the residual oil in the gaps or pores of path 1 is not easy to be completely removed. After a period of time, the accumulated oil slowly oozes out and forms oil stains at the waterproof glue, resulting in suspected oil leakage.

3.2. Factory return test and disassembly check

3.2.1. Return to factory test. Eight pressure equalization capacitors were selected for routine test verification and the test results met the requirements. In addition, a test sample was launched for a water proof test. The gaps in the cover plate were injected into the water droplets to simulate the actual operating conditions on the site. The test results showed no significant change from the non-leaching test samples. One sample was tested with a 420kV proof partial discharge test, and the test results met the requirements.

3.2.2. Disassembly inspection. The disassembly inspection items of voltage equalizing capacitor mainly include appearance inspection, tightening bolt torque inspection of sealing surface, measurement of internal oil pressure and pressure relief oil volume of capacitor, and disassembly inspection of capacitor. The specific disassembly inspection is as follows:

(1) Appearance inspection
Before disassembly, the appearance of 7 voltage equalizing capacitors with oil leakage was inspected. There was no deformation on the sealing end face and no obvious damage on the porcelain bushing of capacitor.

(2) Tightening bolt torque inspection
Check the fastening bolts on the cover plates at both ends of the capacitor, and the results meet the torque requirements (10N · m).

(3) Inspection of internal oil pressure and pressure relief oil quantity of capacitor
When checking the oil pressure, the ambient temperature is 0 ℃. According to the temperature / oil pressure characteristic curve, the oil pressure inside the capacitor should be 0.076 ~0.082mpa, and the amount of pressure relief oil should be between 1600 ± 5% ml. Because of oil leakage in 5 of the 7 voltage equalizing capacitors, the amount of pressure relief oil is lower than the standard requirement.

(4) Disassembly inspection of capacitor
After inspection, it was found that the corresponding cover plate or bottom plate and corresponding sealing ring of the voltage equalizing apparatus with oil leakage in the main seal had burning traces caused by suspected partial discharge.2.2.3 Disintegration check.

Figure 3. Discharge traces of the sealing and the sealing ring of the leakage side cover plate.
3.2.3. Minimum safe operation oil test of voltage equalizing capacitor. In order to further determine the safe voltage of leakage oil equalizing capacitor, three samples were randomly selected to carry out the test of minimum safe operation oil quantity. According to the test results, the test data of the voltage equalizing capacitor after releasing a certain amount of oil meet the requirements of the standard and the technical agreement. In addition, under the condition of low pressure (0.01 MPa), the discharge capacity of equalizing capacitor is 2 / 3, and its ex factory electrical performance can also meet the requirements.

3.3. Material inspection and salt spray test

3.3.1. Failure seal ring detection. In order to eliminate the influence of the material characteristics of the sealing ring (the physical properties of rubber material) and the influence of the sealing ring in the state of electrolyte equalizing capacitor insulating oil, a third party is entrusted to inspect the failure sealing ring. The test results show that the material and physical properties of the seal ring meet the requirements.

3.3.2. Material inspection of sealing end plate. LY12 aluminum rod is selected as the sealing end plate (cover and bottom plate) of voltage equalizing capacitor. According to the chemical composition sampling results conducted by the third party, the chemical composition and its proportion are similar to the standard, indicating that the supply quality of LY12 aluminum bar meets the requirements.

3.3.3. Salt spray test. Sampling of 2 pieces of sealed end plates of JAF250-2000 pressure equalization capacitors was performed. The external party conducted a 24h neutral salt spray test and passed inspections, indicating that the surface treatment quality control was effective and meets the requirements.

3.4. Voltage Equalizing Capacitance Electric Field Calculation

3.4.1. Potential difference theoretical calculation and analysis. The circuit-breaker is in the closing state, and the voltage-equalizing capacitor does not withstand the voltage, and no potential difference can occur. The sealing end plates of the pressure equalizing capacitors and the porcelain sleeve flange are firmly connected with (8) bolts. Under normal operation, they are at the same potential and there is no potential difference, and no discharge occurs during the period.

When the circuit breaker is closed, the peak value of the impact current of the capacitor from the end plate (bottom, cover) through the flange is calculated to be about 3.3 kA at maximum, due to the high frequency of the inrush current: about 2×10 6 Hz, the inductive reactance generated by the screw inductance Large; 8 screws in parallel to produce a total impedance of about 6mΩ or so, get the maximum potential difference of about 20V or so, the potential difference is relatively small. It shows that the sealing structure site is not easy to produce partial discharge and cause similar leakage phenomenon in the sealing part.

At the same time, the black marks on the main sealing surface of the sealed end plate of the oil seepage test product are in a relatively concentrated cluster shape, and there is a large difference from the general discharge marks in an irregular stripe shape, which is not enough to indicate that the discharge is caused by leakage. Oil problem. At the same time, the electric field emulation calculation shows that the electric field at the failure location of the pressure equalization capacitor seal ring is not high enough to make the seal ring failure cause the pressure equalizing capacitor to leak oil.

3.4.2. Electric field simulation

(1) Simulation model
According to the schematic diagram of the structure of the JAF250-2000 voltage equalization capacitor provided, a 2-dimensional simulation model is established as shown in Figure 4 and Figure 5, and the air editing size is 10000mm × 20000mm. Simulation parameters is shown in Table 2.

| Part               | Relative dielectric constant | Part               | Relative dielectric constant |
|--------------------|-----------------------------|--------------------|-----------------------------|
| Metal parts        | 100                         | Viton seals        | 8                           |
| air                | 1                           | Cement layer       | 5                           |
| Porcelain sets     | 6                           | Mandrel            | 6                           |
| Paper gasket       | 3.5                         | water              | 81                          |
| C101oil            | 2.61                        |                    |                              |

(2) Simulation results of existing structures

① Simulation under normal condition

The electric field simulation of voltage sharing capacitor under normal state is shown in Figure 6, Figure 7 and Figure 8.
There are three places where the electric field equipotential lines are relatively dense near the end plate, as shown in the circle in Figure 8. The electric field intensity changes rapidly in these three positions, which may cause defects.

According to simulation calculations, under normal conditions, the maximum electric field intensity at the red circle 1 can be 2.74 kV/cm. The maximum electric field intensity at the red ring 2 metal burr is 1.97 kV/cm. The maximum electric field intensity at the red circle 3 is 6.65 kV/cm. The field strength in the lower right corner is 0.87 kV/cm, the field strength in the upper right corner is 0.84 kV/cm, the field strength in the lower left corner is 1.76 kV/cm, and the field strength in the upper left corner is 0.53 kV/cm in the seal ring.

Simulation under abnormal conditions

In order to simulate the situation that may be encountered in the operation, the right gap of the sealing ring is filled with water, and the electric field simulation calculation is carried out. The results are shown in Figure 9 ~ Figure 11.

There are three locations where the electric field equipotential lines are dense near the end plate, as shown by the red circle in the partially enlarged view of Figure 11. The electric field intensity at these three locations changes relatively quickly and is a location where defects may occur.

According to simulation calculations, the maximum electric field strength at red circle 1 can be 2.74 kV/cm under wet conditions, the maximum value of the electric field strength at the metal burrs at red circle 2 is 0.34 kV/cm, and the maximum value of the electric field strength at the 3 red circles is 6.63 kV/cm. Seal: The field strength in the lower right corner is 0.38 kV/cm, the field strength in the upper right corner is 0.18 kV/cm, the field strength in the lower left corner is 1.70 kV/cm, and the field strength in the upper left corner is 0.39 kV/cm.

In summary, it can be seen that the electric field at the failure location of the pressure equalizing capacitor seal ring is not high enough to make the seal ring fail and lead to voltage leakage in the voltage equalization capacitor.

4. Conclusion

Through the sealing test, return to factory test and disassembly inspection, material inspection and salt spray test, electric field calculation, simulation test verification, and electrochemical corrosion factor analysis, the causes of suspected oil leakage and oil leakage are as follows:

(1) The suspected oil leakage is caused by the pressure equalizing capacitance oil accumulation. The reason for the oil accumulation is that the oil spills out during the vacuum oil injection process. The oil medium penetrates into the pouring cement through the gasket and forms oil accumulation. After a period of time, the accumulated oil slowly seeps out, forming oil stains at the waterproof glue, causing suspected oil seeping phenomenon.

(2) The main reason for the oil leakage of the equalizing capacitor is the electrochemical corrosion on the sealing surface of the sealing end plate.

In order to ensure the safe and stable operation of the circuit breaker, the corresponding rectification measures are proposed:
By adding chamfering design of equalizing capacitor cover plate and strengthening anodic oxidation process control of cover plate, the quality of sealing cover plate of equalizing capacitor is improved and electrochemical corrosion is prevented.

In the vacuum oil injection process, the increased oil injection support shall be used to prevent the oil from entering into the pouring cement.

Strengthen the inspection of the leakage of the equalizing capacitor, and inform the manufacturer to replace the equalizing capacitor in case of leakage.

4. Corrective measures

Reference:
[1] Wu Gaobo, Ruan Jiangjun, Huang daochun, Shu Shengwen, Zhang Kun. Review of voltage sharing capacitance of multi break vacuum circuit breaker [J]. High voltage apparatus, 2011, 47 (03): 77-81
[2] Tang Shiyu, sun Yujiang. Analysis of explosion accident of voltage sharing capacitor of 500kV switch [J]. High voltage apparatus. 2005 (03)
[3] Chen Huagang, preventive test method for electrical equipment [M]. Water conservancy and electric power press, 1994
[4] Qian Guochao, Wang Jinglin. Measurement and analysis of voltage sharing capacitance of 500kV porcelain column circuit breaker [J]. Yunnan electric power technology. June 15, 2001
[5] Zeng Zhaoxiong. Study on the direction of exhaust hole assembly of low oil circuit breaker [J]. Metallurgical power. 1987 (02)
[6] Gong Ruilei, Zhao Jiangtao. Electric field analysis and design of ultra high voltage circuit breaker with shunt capacitor based on ANSYS electrostatic field [J]. High voltage apparatus. 2012 (06)
[7] Zhou Yuan, Li Qian, Peng Xiangyang. Simulation analysis and Countermeasures of voltage equalizing capacitor explosion accident of circuit breaker in Yandu station [J]. China Southern Power Grid technology. 2014 (04)
[8] Xu Guozheng, principle and application of high voltage circuit breaker [M]. Tsinghua University Press, 2000
[9] Zhao Yongchao. Effect of voltage sharing capacitor and its influence on power system [J]. Guangxi electric power technology. September 30, 1995
[10] Wu Deguan, Zhou Yu, Li Weiguo, Li Hongyuan, Xu Yi, Xia Hui. Analysis of a 500kV circuit breaker voltage sharing capacitor fault [J]. High voltage apparatus. 2016 (03)
[11] Qian Guochao, Ma Yi, Zou Dexu, Yan Bing, Zhou Jun, Huang He. Test and analysis of voltage sharing capacitance of circuit breaker break [a]. Internet of things and new power technology - Proceedings of Yunnan Power Technology Forum 2014 [C]. 2014
[12] Qian Guochao, Zou Dexu, Zhou Fangrong, Ma Yi, Zhou Jun, Yan Bing, Huang He. Analysis and comparison of voltage sharing capacitance test methods for circuit breaker fracture [J]. High voltage electrical equipment. 2015 (08)
[13] Liao Minfu, Duan Xiongying, Zou Jiyan, Cong Jiyuan. Three dimensional electric field finite element calculation of vacuum interrupter based on JPCG algorithm [J]. Acta electrical engineering Sinica. 2004