Corrosion and Deposition of HVDC Converter Valve

Pengfei Cui1*, Shengli Guan1, Jianbao Guo1, Guangwu Wang2, Haijun Wang1, Jianye Chen3, Kefeng Huang2, Man Geng2, Weilong Yang2, Longlong Deng1

1Maintenance & Test Center of CSG EHV Power Transmission Company, Guangzhou, Guangdong 510663, China
2Goaland Energy Conservation Tech. Co. Ltd., Guangzhou, Guangdong, 510663, China
3Department of electrical engineering of Tsinghua University, Beijing, 100084, China

*Corresponding author e-mail: meicpf@163.com

Abstract: The corrosion of the light-triggered converter radiator and the fouling of the voltage-equalizing electrode are always the technical problems to be solved in the field of HVDC, which seriously affects the stable operation of the DC system. In this paper, the material properties, manufacturing process and actual running process of radiators are studied deeply through the analysis of composition and morphology. Main reason for the corrosion of radiator is the turbulent corrosion caused by the cold water flushing in the converter valve, and the electrochemical corrosion is only a small part of the corrosion of radiator. At the same time, in order to verify the scaling process of the voltage-equalizing electrode, a test platform was built, and the experiment was carried out by using aluminium ion input acceleration method. The experimental results show that the aluminum ions precipitated by the corrosion of radiators are transferred directionally to the high-potential electrode under the action of electric field to form aluminium hydroxide precipitation. The precipitation of aluminium hydroxide leads to the scaling of the equalizing electrode, which is getting worse every year.

1. Introduction

Aluminum is common heat dissipation material with light weight, good heat transmission and good conductivity properties. Platinum is a white precious metal with excellent conductivity, corrosion resistance and its chemical stability. Aluminum and platinum are widely used in electric power, steel, petroleum, chemical, electronic communications, aerospace and other fields. In HVDC project, aluminum radiators are used in light-triggered thyristor for high efficiency cooling, and platinum electrode are used to balance potential of each branch in the valve. As the long-term operation of the valve, the aluminum radiators corrosion, the pressure equalizing electrode fouling and so on are normal phenomenons. The fouling substance falls and blocks the water pipes of the valve, which led to
the cooling efficiency decline and DC block. It seriously affects the stability of the HVAC/DC system [1-5].

For a long time, the corrosion and sedimentary of the valve components are technical problems to be solved in HVDC field, they are received wide attention from various research institutions around the world. Through the detection analysis and verification test, this paper comprehensively studies the formation mechanism and root cause of aluminum radiator corrosion and pressure equalizing electrode fouling, and provides basis and reference for system optimization and engineering transformation.

2. Experiment

2.1 Detection and analysis

In view of the actual operation and maintenance, converter stations do comprehensive descaling and maintenance every three years. In order to study the corrosion process of the radiator, this paper detects and analyzes the element and content of the material of the equalizing electrode, the electrode fouling sample and the radiator of the ±500kV converter station. The test results are shown in Table 1. The pressure equalizing electrode and the scale sample, the heat sink of the spare part and the heat sink which are dismantled and put into operation for 15 year are shown in Fig. 1, Fig. 2 and Fig. 3.

| Element | Heat sink of the spare part | Scale sample of spare part heat sink | Scale sample of the electrode | Pressure equalizing electrode |
|---------|----------------------------|-------------------------------------|------------------------------|-------------------------------|
| AL      | 98.74 %                    | 98.72 %                             | 95.26 %                      | 0.0054 %                     |
| Pt      | Not detected               | Not detected                        | 0.05 %                       | 99.89 %                      |
| Si      | 0.55 %                     | 0.55 %                              | 0.54 %                       | 0.005 %                      |
| Cl      | Not detected               | 0.03 %                              | 0.24 %                       | Not detected                 |
| S       | Not detected               | 0.02 %                              | 1.64 %                       | Not detected                 |
| Others  | 0.71 %                     | 0.68 %                              | 2.27 %                       | 0.0996 %                     |

Figure 1. Voltage-equalizing electrode and scale deposit
2.2 Verification test

In order to study the formation mechanism of the pressure equalizing electrode fouling, a test platform was built with reference to the ±500kV converter valve water cooling system, and the field conditions were simulated to carry out the verification test, the aluminum ion was adopted to accelerated test. The principle of the verification test platform is shown in Figure 4.
3. Results and analysis

3.1 Material analysis

According to the analysis of the test results, the converter valve radiator is 6060 grade aluminum alloy, the base material is aluminum element, the content is 98.74%, the internal water channel of the spare part radiator has corrosion and rust, the main component of the rust sample is aluminum element, the content is 98.72%, It contains 0.03 % chlorine element and 0.02% sulfur element; the pressure equalizing electrode needle is made of platinum, the content is 99.89%; the main component of the pressure equalizing electrode fouling is aluminum element, the content is 95.26%.

3.2 The research of the aluminum radiators corrosion

3.2.1 Physical performance analysis of aluminum

Pure aluminum has a density of 2.7g/cm³, a melting point of 605°C, a boiling point of 2467°C, no magnetic, good thermal conductivity, and electrical conductivity is only to silver and copper. However, aluminum is active metal element with low-stability. Under natural conditions, the surface of the pure aluminum will naturally form a protective oxide film with a thickness of 1-5 nm, including an outer oxide film and an inner oxide film. As shown in Figure 5.

![Figure 5. Schematic diagram of aluminium oxide film](image)

Under natural conditions, the oxide film is destroyed by external force and will repair itself. However, due to the thinness of the natural oxide film and the existence of porous defects, as shown in Figure 1, the corrosion resistance of the aluminum natural oxide film is limited, which is not enough to be attacked by chloride ions, electrochemical corrosion and fluid scouring. For example, the aluminum oxide film has a pore diameter of 33 nm and a chloride ion diameter of 0.181 nm, so that the aluminum material is extremely susceptible to attack by chloride ions.

3.2.2 Processing and manufacturing corrosion analysis

At present, aluminum radiators in the light-triggered converter valve are processed by vacuum brazing technology, mainly including CNC numerical control processing, drying, vacuum brazing, pressure testing, heat treatment and cleaning, etc., and in the cutting coolant used in the processing of the radiator water channel, flux used in vacuum brazing, and the composite cleaning agent used after the processing are all contain chloride. Because chloride ion has the characteristics of small ion diam-
eter, strong penetrating ability, easy to reach metal surface, easy to adsorb on metal surface, etc., soluble chloride is generated on the metal surface, chloride is easily hydrolyzed, and a large amount of metal ions are generated, resulting in pitting corrosion and formation pitting corrosion. The principle of pitting is shown in Figure 6.

![Figure 6. Schematic diagram of pitting principle of radiator](image)

The spare part radiator rust sample contains 0.03% chlorine element, in order to accurately analyze the corrosion cause, the rust area of the spare part radiator is further cut into for electron microscope scanning analysis. As shown in Figure 7, the area has formed pitting corrosion.

![Figure 7. SEM of spare radiator internal channel](image)

3.2.3 Corrosion analysis during operation

According to the metal corrosion theory, wear corrosion is a type of metal damage formed by the combination of electrochemical corrosion and erosion corrosion. Among them, the erosion corrosion is caused by the relative movement between the fluid and the metal surface, and the formed pits and grooves have certain directivity. Erosion corrosion includes three types of corrosion: turbulent corrosion, cavitation corrosion, and vibration corrosion. The principle of erosion corrosion is shown in Figure 8.
(1) Calculation and analysis

According to the technical parameters of a converter valve of ±500kV, the flow rate of the aluminum radiator is 2.7-3.5L/min, the flow rate of the calculated channel is 2.78m/s, and the Reynolds coefficient Re is 9332. According to the theory of fluid mechanics, the fluid form in the channel is turbulent and has turbulent corrosion conditions.

(2) Morphology analysis

An anatomical work was carried out using an aluminum radiator that has been in operation for 15 years as an analytical sample. After analysis, the aluminum radiator inlet, the bottom of the channel and the inner wall of the rectangular channel are severely corroded; the aluminum radiator outlet and the outer wall of the rectangular channel are less corrosive; there are traces of erosion corrosion and fluid centrifugal force at the bottom of the channel. The corrosion profile of the aluminum heat sink is shown in Figure 9-11.
Figure 11. Surface images of inner and outer wall of radiator water channel

In order to accurately analyze the cause of corrosion, the corrosion region of the radiator is further cut into for an electron microscope scanning analysis. As shown in Fig. 12, it has been detected that an etch pit has been formed in the region, and the etch pit has the directionality of the scouring action.

Figure 12. SEM of radiator running for 15 years internal channel

(3) Process analysis

The inner channel of the radiator is a spiral distribution of Archimedes. The diameter of the inlet of the radiator is Φ15mm, and the cross section of the internal channel is a rectangular waterway with a width of 3mmX and a height of 3mm.

During the live operation of the converter valve, the internal cold water enters the internal water channel from the radiator inlet. As the water passage suddenly narrows, the internal cold water moves at a high speed on the surface of the water channel, and forms a turbulent flow, which produces a shear stress on the surface of the water channel. The aluminum oxide film is peeled off by the shear stress, and the surface of the pure aluminum is exposed in the inner cold water. Under the action of the scouring force and the centrifugal force, the bottom of the water channel and the outer wall of the water channel are continuously worn, and the metal aluminum dissolves into the inner cold water in the form of hydrated ions to form wear. The converter valve has been running for many years, and turbulent corrosion has been increasing year by year [6-8].

(4) Electrochemical corrosion analysis

Taking a DC converter valve of ±500kV as the research object, the maximum voltage between adjacent radiators is 0.98kV, and the leakage current of aluminum radiator is 59.6nA-1.59uA. According to Faraday's law, the corrosion rate of a single aluminum radiator is calculated to be 4.51 nm/y-0.121 um/y, and the total electrochemical corrosion of a total of 1008 aluminum radiators is 1.560 g.

According to the actual project operation and maintenance, the average annual corrosion of the
aluminum radiator of the single-pole converter valve is about 34g, and the electrochemical corrosion amount only accounts for 5% of the total corrosion of the actual project for one year. Therefore, electrochemical corrosion is not the main cause of corrosion of aluminum radiators.

(5) Summary
During the operation of the aluminum radiator, the main cause of corrosion is turbulent corrosion, and the electrochemical corrosion is only a small part of the corrosion of the aluminum radiator.

3.3 Research on pressure equalization electrode scaling

3.3.1 Mechanism analysis
After the oxide film on the surface of the aluminum radiator is washed away, the pure aluminum surface of the heat sink substrate is worn and dissolved in the cold water. The aluminum element loses electrons and precipitates aluminum ions, and is freed from the inner cold water of the radiator channel. Due to the internal cold water have a large number of hydroxide ions, aluminum ions and hydroxide ions react rapidly, produce meta-aluminate, which move to the high-potential platinum pressure equalizing electrode under the action of high-speed water flow and electric field, and adsorb around the pressure equalizing electrode, concentration and condensation, production of aluminum hydroxide precipitation, and finally accumulated into scale [9]. The chemical process of the pressure equalization electrode scaling is shown in Equation 1, Equation 2, and the physical process of the pressure equalization electrode fouling is shown in Fig.13

$$AL^{3+} + 4OH^- = ALO_2^- + 2H_2O$$  \hspace{1cm} (1)

$$ALO_2^- + H^+ + H_2O = AL(OH)_3 \downarrow$$  \hspace{1cm} (2)

![Figure 13. Schematic diagram of scaling process of Voltage-equalizing electrode](image)

3.3.2 Test analysis
Relying on the test platform, deionized water is used as the test source water [10], injected into the water circulation pipeline of the test unit, aluminum ions are added, and the high-voltage direct current test power source is connected to accelerate the scaling process of the pressure equalizing electrode.
The test period is 30 days. The test technical parameters are shown in Table 2.

| Kind                | Parameters     | Value     |
|---------------------|----------------|-----------|
| Raw water           | pH             | 7.56      |
|                     | Conductivity   | 0.15us/cm |
|                     | Volume         | 2.5L      |
| Recycled water      | pH             | 8.16      |
|                     | Conductivity   | >100us/cm |
| Electric field env-| Voltage        | 1000VDC   |
| ronment             | Electric current| 14.5mA    |

The test results show that the high potential equalizing electrode is severely fouled, and the thickness of the scale layer is 1 mm, as shown in Fig. 14; the fouling of the low potential equalizing electrode is not obvious. The test is consistent with the actual engineering situation.

4. Conclusion

The corrosion and deposition of the high-voltage direct current triggering converter valve are formed in the comprehensive promotion of various links and factors. The conclusions are as follows:

(1) The thyristor heat sink is made of aluminum, and its natural oxide film has pore defects and insufficient corrosion resistance.

(2) In the process of brazing, the aluminum radiator uses a large amount of chloride-containing cutting coolant, flux and composite cleaning agent. However, after the processing is finished, it is not thoroughly cleaned, and the chloride residual liquid stays inside the radiator channel which causes pitting to occur.

(3) During the live operation of the converter valve, the aluminum radiator has a long and narrow water channel, high flow velocity, turbulence, fluid scouring force and centrifugal force, and the wear phenomenon is obvious. Turbulent corrosion is the main effect of corrosion of aluminum radiators, while electrochemical corrosion is only a small part of the corrosion of radiators.

(4) The pressure equalizing electrode needle is made of platinum, and its material properties are stable. However, due to the turbulent corrosion of the radiator, aluminum ions are precipitated, and
under the action of the electric field, the high-potential platinum electrode needle is directionally migrated to form aluminum hydroxide precipitate, which causes the scale electrode scaling to increase year by year.

5. Acknowledgments

This work was financially supported by Scientific Research Project of CSG EHV Power Transmission Company (CGYKJXM20160093).

References

[1] Wang Y Y, Hao Z J, Lin R. Primary analysis on corrosion and deposit in valve cooling system of Tianguang HVDC project [J]. High Voltage Engineering, 2006, 32(9) 80-83.
[2] Tian X W, Yang J M, Zhang W P. Analysis and improvement suggestions of grading electrode o ring leakage at Tian-Guang HVDC engineering [J]. Modern Science, 2008, 12(8) 68-70.
[3] Zhang G S, Feng Z W. Analysis and Modification Unstable Factors of valve cooling system in Tianshengqiao convert station [J]. Guangxi Electric Power, 2010, 03: 29-31.
[4] Yao Q X, Rao H G. Valve cooling system pitfall analysis and treatment in Yidu converter station[J]. Central China Electric Power, 2010, 05: 56-58.
[5] Jiang H B, Zhai B, He X Z. Reliability analysis and assessment of converter station valve cooling system[J]. Northeast Power Technology, 2014, 03: 52-55.
[6] Zhu J, Zhang Q B, Chen Y, et al. Progress of study on erosion corrosion [J]. Journal of Chinese Society for Corrosion and Protection, 2014, 3: 199-210.
[7] N Dr Holweg. Siemens Investigation Report of Scaling Phenomenon on Grading electrodes in Thyristor valve Cooling Circuit. Erlangen, Siemens Technical Note, 07. 02. 2007.
[8] P O Jackson, B Abrahamsson, D Gustavsson. Corrosion in HVDC vavle cooling system[J]. IEEE Transaction on Power Delivery, 1997, 12(2): 1049-1052.
[9] Zhang P D, Hao Z J, Liu H T. Principle and implement of improving Guiguang HVDC valve cold voltage sharing pole [J]. Electric Engineering, 2008, 29(12): 16-17.
[10] Li Y. Improvement of operation of TianGuang HVDC engineering cooling water cooling system [J]. Journal of Guizhou Electric Power Technology. 2009, 12(1):25-26.