IOP Conference Series: Materials Science and Engineering

PAPER • **OPEN ACCESS**

Application of numerical calculation to simulation analysis of stray current corrosion in radiator of HVDC Converter Valve

To cite this article: Pengfei Cui *et al* 2020 *IOP Conf. Ser.: Mater. Sci. Eng.* **768** 062105

Application of numerical calculation to simulation analysis of stray current corrosion in radiator of HVDC Converter Valve

Pengfei Cui[1,*], Shengli Guan[2], Jianbao Guo[1], Guangwu Wang[2], Haijun Wang[1], Jianye Chen[3], Kefeng Huang[2], Man Geng[2], Weiwong Yang[2], Longlong Deng[1]

[1]Maintenance ＆ Test Center of CSG EHV Power Transmission Company, Guangzhou, Guangdong 510663, China

[2]Goaland Energy Conservation Tech. Co. Ltd., Guangzhou, Guangdong, 510663, China

[3]Department of electrical engineering of Tsinghua University, Beijing, 100084, China

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

Abstract: According to the electrical structure design of the converter valve, the stray current scattered in the water path of the converter valve tower is coupled in the internal waterway of the aluminum radiator. It promotes the occurrence of corrosion on the inner surface of the waterway. However, due to the wide range of stray current in the valve tower distribution pipe, many factors affecting the properties of fluid and the actual engineering not allowed to be measured, and so on. For a long time, the corrosion of converter valve radiator has always been an urgent technical problem to be solved in the field of DC transmission. It has received extensive attention in various research institutions around the world. In this paper, according to the distribution pipe of 500kV light-triggered converter valve tower, the structure model and equivalent circuit model of the water path are built and the mechanism of stray current corrosion of aluminum radiator is analyzed. At the same time, the circuit simulation software is used, and according to Faraday's law, the stray current, corrosion rate and annual corrosion rate of aluminum radiator in distribution pipe were calculated quantitatively. According to the numerical calculation results, the corrosion of aluminum radiator is compared with that of actual engineering aluminum radiator, the primary and secondary relationship of stray current corrosion in aluminum radiator corrosion is put forward, which provides the basis and reference for system optimization and engineering transformation.

1. Introduction

Al is a common heat dissipation material, which has the characteristics of light weight, great heat transfer and conductivity; P_t is a white precious metal with excellent electrical conductivity, corrosion resistance and chemical stability. Al and Pt are widely used in power, steel, petroleum, chemical industry, electronic communication technology, aerospace and other fields. In HVDC project, the light-triggered converter valve uses aluminum radiator to achieve efficient cooling of thyristor, and uses platinum electrode to equalize the branches of waterway potential in the valve section. With the long-term operation of converter valves, corrosion of aluminium radiator and scaling of platinum equalizing electrodes are widespread. Shedding of scale easily results in the clog of cooling water pipeline in valve tower, and reduces the cooling effect of thyristor. The DC locking events usually occur, which seriously affects the stable operation of DC system [1-6].

According to the electrical structure design of the converter valve, stray currents in the water channel of the converter valve tower encounter in the internal water channel of aluminum radiator, which promotes the corrosion of inner surface of the water channel. Due to the wide range of stray current in the water distribution pipeline of valve tower, many influencing factors of fluid and the inability to measure in actual engineering, the corrosion of converter valve radiator has always been a technical problem to be solved urgently in the field of DC transmission for a long time, which has been widely concerned by many research institutes all over the world. In this paper, a waterway structure model and equivalent circuit model were built according to the water distribution pipeline of ±500kV light-triggered converter valve tower, and the corrosion mechanism of stray current in aluminum radiator was analyzed. Meanwhile, stray current in water distribution pipeline and the corrosion rate and annual corrosion amount of aluminum radiator were calculated quantitatively based on Faraday's Law by using the circuit simulation software. According to the comparison of numerical results and corrosion situation of aluminum radiator in actual engineering, the primary and secondary relationship of stray current corrosion in aluminum radiator is proposed, which provides basis and reference for system optimization and engineering transformation.

2. Establishment of model

2.1 Waterway structure model

Dc project of ±500kV uses 12 pulsating light-triggered thyristor converter valves, and the valve tower is designed as quadruple valve structure, as shown in Figure 1.

Figure 1. ±500kV HVDC converter valve

Each single valve consists of 3 valve assemblies, and each valve assembly consists of 2 valve section. Each valve section consists of 2 PVDF inlet and outlet manifolds, 28 FEP aluminum radiator inlet and outlet capillaries, 14 aluminum radiators and 4 platinum equalizing electrodes. According to the actual installation node of each water pipe, the subsection modeling was built, in which the decomposition section of collection pipe is R1-R26 and T1-T4, the decomposition section of the water-cooled resistance intake pipe is D1-D14, the decomposition section of the radiator intake pipe is L1-L14, and the decomposition section of the radiator outlet pipe is L15-L28. The water structure model of the valve section is shown in Figure 2.

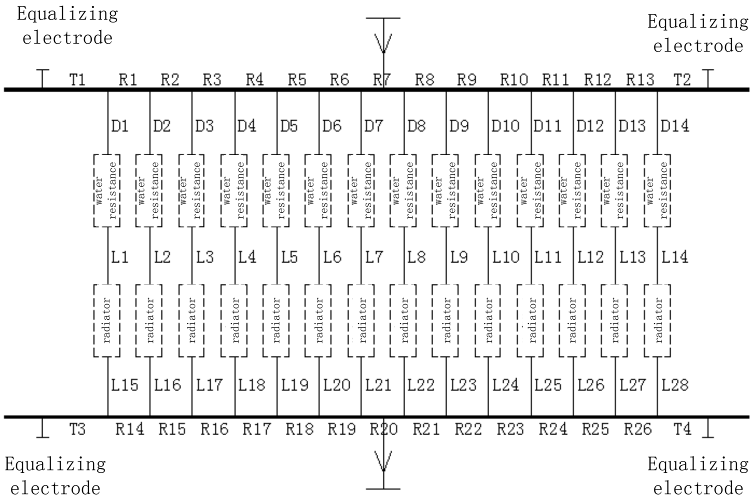

Figure 2. Structural model of valve section waterway

2.2 model of equivalent circuit

1) Calculation of withstand voltage between adjacent aluminum radiators

The rated line voltage of a single valve in a converter station is 209.7kV, the amount of single valve thyristors is 78, the trigger Angle of the thyristor is 15° in normal operation, the maximum withstand voltage of a single thyristor is the maximum withstand voltage between the adjacent two radiators, which is 0.98kv.The calculation is shown in equation 1.

$$U_{\max} = \sqrt{2} \times U_L \times \sin(\alpha) \quad (1)$$

Where: U_L is rated line voltage of single valve; α is thyristor trigger Angle.

2) Calculation of water resistance in each section of valve

According to the water structure model of the valve section, the internal cooling circulating water in the confluence section, water-cooling resistance inlet water pipe and radiator inlet and outlet water pipe is equivalent to resistance. Then the resistance calculation of each water pipe section is shown in equation 2.

$$R = \rho \times \frac{L}{S} = \frac{1}{\rho_0} \times \frac{L}{S} \quad (2)$$

Where: ρ is the density of water; ρ_0 is the conductivity of water; L is the length of water pipe section; S is the surface area inside the water pipe.

3) Equivalent model construction and leakage current calculation

According to the distribution and installation position of each waterway and combined with the circuit simulation software, the waterway structure model is equivalent to the circuit simulation model, as shown in figure 3.

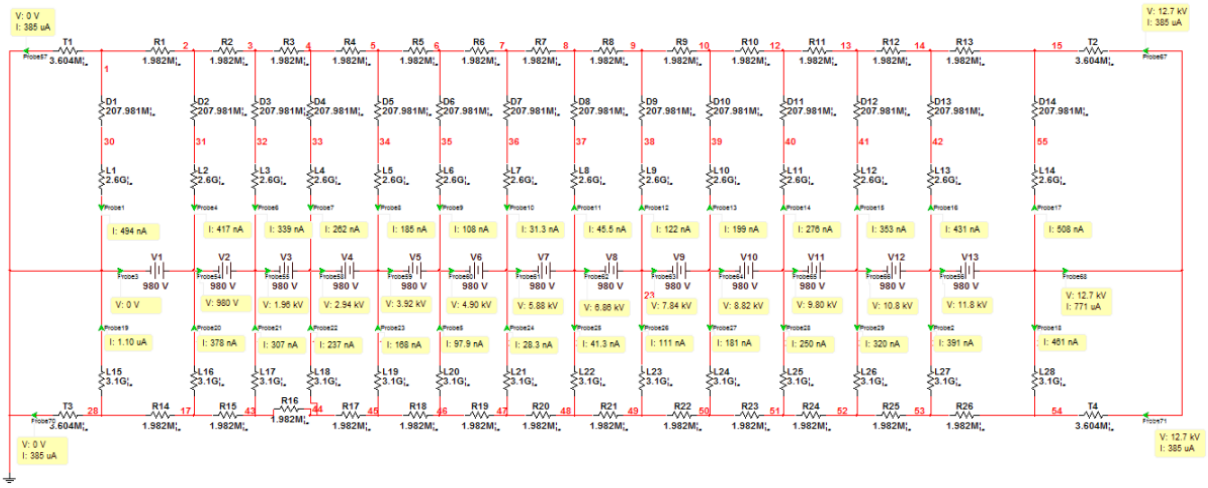

Figure 3. Equivalent circuit model

According to the requirements of GB/ T30425-2013 Water Cooling Equipment for Converter Valves for High Voltage Direct Current (HVDC) Power Transmission, the electrical conductivity of internal cold water should be ≤0.5us/cm. According to the analysis of the severest working condition in which the conductivity of internal cold water is 0.5us/cm [7], the resistance of each section of waterway in the valve section is calculated by formula 2, as shown in table 1.

A single aluminum radiator is a double-sided watercourse, and the double-sided watercourse is a rectangular watercourse structure of Archimedes' spiral, in which the length of the single-sided watercourse is 2.4m and the width of the watercourse is 3mm.According to the equivalent circuit simulation model, stray current and current density of each section of waterway are measured and calculated, as shown in table 2.

Table 1. Resistance of valve section waterway

Code	Name	Texture	external diameter of pipe cm	Resistance MΩ
T1	Water inlet manifold	PVDF	4.0	3.604
T2				3.604
R1…R13				1.982
T3	Water outlet manifold			3.604
T4				3.604
R14…R26				1.982
D1…D14	Branch capillary of water cooling resistor	FEP	0.8	207.981
L1…L14	Inlet water branch capillary of aluminum radiator	FEP	0.8	2600
L15…L28	Outlet water branch capillary of aluminum radiator	FEP	0.8	3100

Table 2. Stray current in water channel on inner surface of radiator

Various waterways	Stray current of each radiator A	Surface area of each radiator's double-sided waterway cm^2	Current density of each radiator's double-sided waterway A/cm^2
L1—L15	1.59E-06	144	1.11E-08
L2—L16	7.95E-07	144	5.52E-09
L3—L17	6.46E-07	144	4.49E-09
L4—L18	4.99E-07	144	3.47E-09
L5—L19	3.53E-07	144	2.45E-09
L6—L20	2.06E-07	144	1.43E-09
L7—L21	5.96E-08	144	4.14E-10
L8—L22	8.68E-08	144	6.03E-10
L9—L23	2.33E-07	144	1.62E-09
L10—L24	3.69E-07	144	2.56E-09
L11—L25	5.26E-07	144	3.65E-09
L12—L26	6.73E-07	144	4.67E-09
L13—L27	8.22E-07	144	5.71E-09
L14—L28	9.69E-07	144	6.73E-09

3 .Results and analysis

3.1 Mechanism analysis

The stray current flowing in the water channel of the converter valve tower is coupled in the water channel inside the aluminum radiator, causing corrosion on the inner surface of the water channel. Stray current corrosion is essentially electrochemical corrosion [8-9], and its corrosion process is shown in Equation 3 and Equation 4.

$$Al^{3+} + 4OH^{-} = AlO_2^{-} + 2H_2O \quad (3)$$

$$AlO_2^{-} + H^{+} + H_2O = Al(OH)_3 \downarrow \quad (4)$$

3.2 Corrosion rate and corrosion calculation

According to Faraday's law, the stray current corrosion rate is proportional to the current density, as shown in Equation 5.

$$C_R = \frac{i \times A_W}{Z \times F \times \rho} \quad (5)$$

Where: C_R is the resistivity of water; i is the current density; A_W is the molar mass of the metal; Z is the number of transferred electrons; F is the Faraday constant; ρ is the density.

The ±500kV converter valve contains 14 aluminum radiators per valve section and a total of 1008 aluminum radiators per pole. Combined with the stray current value of the equivalent circuit simulation model, the annual corrosion rate and corrosion amount of the surface of each aluminum radiator channel in the ±500KV converter valve every year can be calculated, as shown in Table 3.

Table 3. Corrosion of radiator

Various water-ways	Current density of each radiator's double-sided waterway A/cm^2	Corrosion rate of each radiator's the inner surface mm/y	Corrosion rate of each radiator cm^3	Corrosion weight of each radiator g
L1—L15	1.11E-08	1.21E-04	1.74E-03	0.0047
L2—L16	5.52E-09	6.01E-05	8.66E-04	0.0023
L3—L17	4.49E-09	4.89E-05	7.04E-04	0.0019
L4—L18	3.47E-09	3.77E-05	5.44E-04	0.0015
L5—L19	2.45E-09	2.67E-05	3.85E-04	0.0010
L6—L20	1.43E-09	1.56E-05	2.24E-04	0.0006
L7—L21	4.14E-10	4.51E-06	6.49E-05	0.0002
L8—L22	6.03E-10	6.57E-06	9.46E-05	0.0003
L9—L23	1.62E-09	1.76E-05	2.54E-04	0.0007
L10—L24	2.56E-09	2.79E-05	4.02E-04	0.0011
L11—L25	3.65E-09	3.98E-05	5.73E-04	0.0015
L12—L26	4.67E-09	5.09E-05	7.33E-04	0.0020
L13—L27	5.71E-09	6.22E-05	8.95E-04	0.0024
L14—L28	6.73E-09	7.33E-05	1.06E-03	0.0029

According to three of the severe following: all the corrosion of the aluminum heat sink are the corrosion of the stray current , the aluminum ions generated by the corrosion of the aluminum heat sink are all directionally migrated to the pressure equalizing electrode and the scaled material of the pressure equalizing electrode is all $Al(OH)_3$, and combined with the calculation of the stray current of the corrosion rate and the corrosion amount, the analysis is as follows : the corrosion weight of aluminum radiator in each valve section is 0.023g, the annual corrosion amount of all radiator aluminum is 1.7g; the annual scaling of all equalizing electrodes is 4.8g; due to the pressure equalizing electrode needle it is made of platinum and has a cylindrical structure with a diameter of 2 mm and a length of 40 mm. The annual scale of the single-pressure electrode is only 0.018 mm.

However, according to the actual DC engineering operation and maintenance situation, the ±500KV single-pole light-triggered converter valve contains 1008 aluminum radiators and 432 equalizing electrodes. The converter valve descales once every 3 years, the annual scale thickness of a single equal-pressure electrode is about 0.3mm, and the annual fouling amount of all the pressure equalizing electrodes is 97.5 g. Since the aluminum element of the scale electrode of the pressure equalizing electrode is corroded by the aluminum radiator, the annual corrosion amount of the aluminum single element of the single-pole converter valve is 33.8 g.

4. Conclusion

The stray current is common in the water distribution pipeline of HVDC converter valve. The annual corrosion of aluminum radiator corrosion caused by stray current is 1.7g, accounting for only 5% of the total corrosion of 33.8g. Therefore, stray current corrosion is not the main effect of corrosion of aluminum radiators of ±500KV converter valves. Stray current corrosion is only a small part of the corrosion of aluminum radiators. The main cause of corrosion of aluminum radiators is non-electrical corrosion [10].

IOP Conf. Series: Materials Science and Engineering **768** (2020) 062105 doi:10.1088/1757-899X/768/6/062105

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