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Application of Evaporative Cooling Technology in HDVC Converter Station

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Abstract – Converter valve cooling device as the heat exchanger, is known as the converter valve's blood circulation system, Inefficiency of the equipment will not only lead to the component overheating damage, but also serious DC system outage. Therefore, reliable HVDC valve cooling system is essential for the HVDC transmission system. In this article, analysis on the two-phase flow heat transfer characteristics and security of the evaporative cooling technology are provided, the technology's advantage and feasibility are discussed.

Keywords: Evaporative cooling, Converter station, Two-phase flow, Temperature distribution

1. Introduction

In DC transmission project, converter station is a system for energy conversion from AC to DC and from DC to AC, it is the core equipment in HVDC transmission system. In the past ten years, high voltage and high power thyristors were used in HVDC converter valve, effectively improved the DC transmission performance and reliability, promoted the development of HVDC, and attracted the world wide attention. Cooling system as an important part of the converter station, plays an important role to the safe, reliable operation of the converter station [1]-[3].

Converter valve, which consists of thousands of thyristors and has very high demanding on thyristors reliability, plays an very important role in HVDC transmission project. Thyristor usually has very high demanding on its working temperature, with the rising of its working temperature, thyristor's reliability may drop dramatically, this is what is so-called the temperature barrier effect of the electric device, and it greatly restricts the performance of thyristor. Therefore, selecting effective cooling method is an important task to make full use of the device and to improve the reliability of the system.

The Institute of Electrical Engineering of Chinese Academy of Sciences has been engaged in the evaporative cooling technology research for decades. Based on its research, it proposed the inner evaporative cooling system for the high power converter valve, the cooling system is based on the current vertical structure of the converter valve tower, it gives full play to the advantages of evaporative cooling technology to eliminate water fouling, leaks, system complexity and other hidden faults of conventional cooling systems, and it is a new, high efficiency, high reliability, and very promising cooling method [4].

In this article, analysis on the two-phase flow heat transfer characteristics and security characteristic of the evaporative cooling technology are provided, the technology's advantage and feasibility are discussed.

2. Structure of the Evaporative Cooling Device for the Converter VALV

The evaporative cooling structure for the converter valve is as shown in Fig. 1. The heating elements in the system are damping resistor and the thyristor. The cooling of the thyristor is the indirect cooling, in Fig. 1, the evaporative cooling radiator is a cavity body, and the radiator surface is

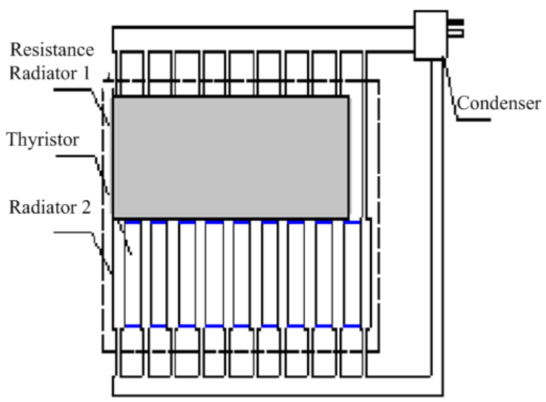

Fig.1. The evaporative cooling structure for converter valve

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in contact with the thyristor surface. When the cooling medium flows inside the cavity body, heat from the thyristor will be absorbed and the cooling medium will be transformed from liquid into gas. The gas medium will exchange heat in radiator and becomes to liquid and flow back to the cavity body. Cooling of the thyristor is therefore achieved by the circulation of the cooling medium. On the other hand, the damp resistor is immersed in the cooling medium to achieve the cooling of the device [5]-[6].

3. Evaporative Cooling Model and Numerical Analysis

Evaporative cooling technology follows the medium boiling heat transfer theory to achieve the cooling on heating parts, according to the boiling heat transfer theory, improving the boiling heat transfer coefficient will improve the heat transfer efficiency, and therefore lower surface temperature of the heating parts can be achieved.

During the cooling circuit design, the boiling heat transfer theory was applied to analyse the system's two-phase flow resistance pressure drop, and the finite element analysis software such as Ansys was been used for simulating different radiator structures and for analyzing their heat transfer efficiency, such efforts provided the theoretical base for the cooling system's radiator structure design. In our analysis, we use the Chen's two-phase heat transfer equation to analyze the temperature distribution of thyristor under evaporative cooling [7]-[8].

Chen's two-phase heat transfer equation is as follows,

$$h = h_{mac} + h_{mic} \tag{1}$$

Forced convective heat transfer coefficient is calculated according to Dittus-Boelter, such as,

$$h_{mac} = 0.023 R_{el}^{0.8} p_{rl}^{0.4} \left(\frac{k}{D}\right)_l F \tag{2}$$

Nucleate boiling heat transfer coefficient is calculated from Forster-Zuber relationship equation, such as,

$$h_{mic} = 0.00122 \left(\frac{k_f^{0.79} c_{pl}^{0.45} \rho_{in}^{0.49}}{\sigma^{0.5} \mu_l^{0.29} h_{in}^{0.24} \rho_g^{0.24}} \right) \Delta t_0^{0.24} \Delta P_0^{0.75} S_0 \tag{3}$$

where,

$$F := 2.35\left(X_{tt} + 0.213\right)^{0.735} \tag{4}$$

$$X_{tt} = \left(\frac{\rho_g}{\rho_l}\right)^{0.5} \left(\frac{\mu_l}{\mu_g}\right)^{0.1} \left(\frac{1-x}{x}\right)^{0.9} \tag{5}$$

$$R_{f0} := \frac{u \cdot (1-x) \cdot d_e \cdot \rho_l}{\mu_l} \cdot F^{1.25} \cdot 10^{-4} \tag{6}$$

where, S_0 is the boiling suppression factor, respectively:

$$S_0 := \left(1 + 0.12 R_{f0}^{1.14}\right)^{-1} \tag{7}$$

From the equation we can tell that the parameters for the flow rate *u*, the channel structure *D* and the gas rate *x* do have great influence on the heat transfer capability. Boiling in confined space is an effective way for enhancing the heat transfer. Therefore, we decided the analysis of the effect of the medium channel structure to the heat transfer was as the first task, and a simulation with Ansys was also conducted to analyze the temperature distribution of the thyristor surface in condition when the heat loss power was at 1.5kw.

Temperature distribution simulation results of the thyristor under evaporative cooling are shown in Fig. 2.

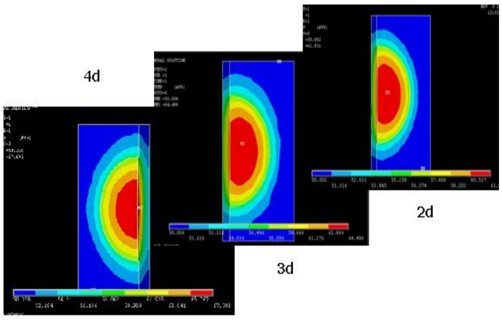

Fig. 2. Temperature distribution of radiator surface using different evaporative cooling channel structure under 1.5kw heat loss power.

In Fig 2, using the classical Chen's two-phase heat transfer principle to analyze the temperature distribution of the thyristor under evaporative cooling, ,the simulation result shows that after using the evaporative cooling, the cooling medium's boiling temperature is at about 50℃, the maximum surface temperature in heating part is at about 68℃, if the circulation in the cavity body can be improved, the surface temperature can reduce more than 6℃. The calculation result also complies with the fact that saturated flow boiling will help to achieve high coefficient and low temperature difference of heat transfer. Medium boiling in narrow channel will enhance the heat transfer because less medium in the flow channel will intensify the nucleate boiling and increase the vaporization of the medium. The liquid film will then become thinner and the heat transfer coefficient will be increased. However the increasing of the gas rate will also lead to the increasing of circulation resistance at the same time. High circulation resistance may cause the drop of heat transfer efficiency and may lead to the thyristor surface temperature rise. Therefore it is necessary to take into account of the flow resistance as well as the heat transfer coefficient during the circulation loop design.

4. Test Result Analysis

An experiment test was conducted to test the correctness of the theoretical analysis and to test the actual effect of the evaporative cooling to the converter valve. The testing model is shown in Fig. 4. The circuit design of the testing model includes 6 diodes connected in series to simulate the heat loss of the converter valve thyristor under practical conditions; the power supply in the circuit is rectifier transformer, which outputs DC output. In test model, the radiator from left to right, 1, 3, 5, 7 thyristor module use the same structure of radiator 1, 2, 4, 6 thyristor module use the same structure of radiator 2. The thermocouple was buried in the case of the thyristor to measure the surface temperature of the thyristor.

Fig.4. Testing Model

In testing, the thyristor is in uninterruptible power charged state, in order to simulate the worse working conditions. When the heat loss is at about 1.5KW, testing results shown in fig 5 demonstrate that the average temperature of the thyristor surface is no more than 80℃, different radiator structures result in the temperature difference at about 5.5℃. The test results are basically consistent with the simulation results Fig 2, and it demonstrates that the medium channel structure does affect the heat transfer efficiency.

Fig. 6 is the Infrared thermal image of the temperature distribution of the surface between thyristor and radiator. The image demonstrates that the temperatures of the contact surface between the 6 thyristor modules and their radiators are evenly distributed, and the maximum temperature of the radiator surface is at about 69℃, it also demonstrates that the surface temperatures of radiators for 1, 3, 5, 7 thyristors are higher than the temperatures of radiators for 2, 4, 6 thyristors, this is consistent with the simulation results. The testing results also demonstrate that the radiators temperatures are below the national standard, so that the evaporative cooling technology is feasible for the converter valve cooling. Moreover, because the heat exchange surface in contact with the cooling medium is the boiling surface, the radiating surface is the isothermal surface, so that the temperature is evenly distributed.

From Figs. 5 and 6, we can tell that there is relatively large temperature difference between the thyristor case and the radiator surface; this is caused in fact by the machinery accuracy. Because there is gap between the contact surfaces, that will induced the thermal resistance in between, therefore in practical use, the designer is necessary to pay attention to minimize the surface contact gap.

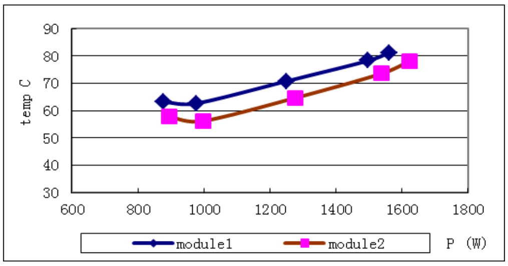

Fig. 5. Surface temperature of the thyristor case

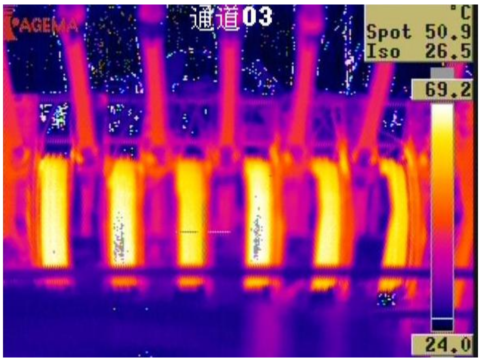

Fig. 6. Temperature distribution of thyristor and radiator surface

5. Security Analysis

Compared with water cooling and air cooling, the biggest difference of evaporative cooling is the cooling performance of its cooling medium. Moreover, the system structure of evaporative cooling is also quite different due to the different heat transfer mechanism. Therefore, in terms of the security of the evaporative cooling technology, our analysis will be focused on the issues such as the performance of the cooling medium, the system structure as well as their impact to the environment.

5.1 Performance of the Cooling Medium

Evaporative cooling medium has good electrical properties, the medium volume resistivity can reach up to 107MΩ.cm and the clean dielectric breakdown voltage can be up to 20 kV/mm or above, therefore it provides better insulation than the air and the deionized water, and equals to the transformer oil. These properties made it suitable for the high voltage environment. Moreover, the medium has good chemical and physical stability, therefore will help to avoid the freezing, frosting and ice problems of water cooling. The medium has good insulation property, therefore it can be used to eliminate arcing and to suppress the partial discharge, and the system reliability can be improved [9].

5.2 System Structure

Evaporative cooling medium enters into the converter valve radiator through self circulation, the cooling medium absorbs the heat from the thyrioster and changes to the gas state, the gas will be cooled down in the external cooling system and changes to the liquid state, the liquid will enter into the radiator again and starts next circulation. In this way, the evaporative cooling system structure can be relatively simple, and need only several operation monitoring parameters, therefore will reduce the workload of system operation and maintenance.

5.3 Impact to the Surrounding Equipment and the Environment

Evaporative cooling system is a non-pump self-circulation system, and it has no noise. Both the air-cooling and the water-cooling system on the other hand have the pump in running and have noise.

From the above analysis it shows that, in terms of the cooling medium, system structure design, and the requirement for the insulation in high-voltage environment, evaporative cooling has its unique advantages over the conventional cooling methods.

6. Conclusion

From the above theoretical calculations and experimental analysis it shows that, for high power DC converter valve power electronic equipment, using evaporative cooling technology for its thyristor, cooling, thyristor case surface temperature will not exceed 80 ℃, satisfys the national standard to thyristor cooling. Moreover, evaporative cooling system is a self-circulation system, the power supply system and the external circulation system necessary for the water cooling can be eliminated, system running pressure is lower and higher reliability can be achieved. Therefore, in terms of heat dissipation, system structure design, and high-voltage environment requirements for the insulation performance, evaporative cooling technology has its unique advantages over the conventional cooling methods, and is suitable for cooling of SVC, DC converter valve stations and other high-power devices.

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