Analysis and Control Strategy of Scaling Difference of Spray Towers of the Valve Cooling System in Converter Station

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Abstract: The valve cooling system of converter station plays a very important role in the DC transmission project, and it is important to keep the system stable running. It is found that great scaling difference appeared among three spray towers of the valve cooling system in Tianshengqiao converter station during overhaul, and this phenomenon seriously affects the stability and effective operation of valve cooling system. Through theoretical analysis and experimental study, this paper reveals the main reason of the scaling difference of the surface of heat exchanger coil, and puts forward the control strategy for the Tianshengqiao converter station. After one year of running, the scaling difference of the surface of heat exchanger coil significantly reduced, and this shows that the effect of improvement is good.

Introduction

High-voltage direct current(HVDC) transmission technology has got the attention of countries all over the world, and converter valve is one of core equipment of HVDC transmission project, and its efficient operation has great significance for the transmission project. Valve cooling system will guarantee converter valve keep long-term stable running by taking away the heat produced by the valve components to atmospheric and avoiding converter valve components overheating. Valve cooling system is generally divided into inside cooling water circulating system and outside cooling water circulating system[1]. Finished heat exchange with components, inside cooling water is cold by outside cooling water in spray tower. Closed cooling tower is used by Tianshengqiao converter station of China Southern Power Grid to cool down inside cooling water. Closed cooling tower belongs to the indirect contact cooling tower, and cooling water is cycled and sprayed on the surface of heat exchange coil to take away heat. Because of evaporation of spray water, ion concentration become higher and higher. Especially as scale ion concentration reaches a certain extent, scale is formed in the outer wall of heat exchange coil scale, thus affect the coil heat dissipation.

In January 2013, during the maintenance, we broke open three cooling tower of Tianshengqiao converter station to overhaul and found that 3# tower outside cooling water pipes and heat exchange coil surface scale very seriously, and 2# tower slightly better than 3# but still seriously, but it is curious that 1# tower has a little scaling on both outside cooling water pipes and heat exchange coil surface. Scaling differences phenomenon is found between three cooling tower in the context of same raw water quality and cooling tower and pump operating conditions. The result of measurement is that thickness of scaling on coil surface of 1#, 2# and 3# tower respectively are 0.80mm, 2.05mm and 3.20mm. That suggests that there are still some factors affect the scaling of

cooling tower. If we could find out the main factors which cause the scaling differences and control these factors, it will be helpful for converter station to solve the problem of scale differences. This paper analyzes the reasons of scaling differences and makes related experiments, and finally develops a control strategy for scaling difference.

Theory Analysis

Factors of operation conditions

Operation condition has a great influence on the fouling in the converter station valve cooling system, such as spray water temperature, water quality, water flow rate and pipe pressure will cause fouling[2].

Spray water temperature. Temperature can affect ion saturation. Generally, the water solubility of $CaSO_4$ and $CaCO_3$(main scaling components) will reduce as water temperature increases[3]. We analyzed the water used in cooling system of Tianshengqiao converter station, and found that the main scaling component is $CaCO_3$. When water temperature increases, solubility of $CaCO_3$ fall to saturation, and then $CaCO_3$ precipitated and attached in the surface of the heat exchange coil to form scale. At the same time, $Ca(HCO_3)_2$ will decompose into $CaCO_3$ as water temperature increases, that will accelerate scaling.

Pipe pressure. Equation of $Ca(HCO_3)_2$ thermal decomposition reaction can be shown as follows:

$$Ca(HCO_3)_2 \leftrightarrow CaCO_3\downarrow + CO_2\uparrow + H_2O \tag{1}$$

When the pressure drop, the solubility of CO_2 in water drops, the balance of reaction turning to right, that promotes precipitation of $CaCO_3$, and then promotes scale[4]. In the spray system, the pressure of spray water on heat exchange coil surface is atmospheric pressure. While the pressure of spray water in pipes is larger than atmospheric pressure, because water in pipes received the pressure from water pump. So, the solubility of CO_2 in water in pipes is higher than in water on heat exchange coil surface. After the spray water is jetted from the shower nozzle, the pressure of water falls down sharply, that accelerates precipitation of $CaCO_3$, and then accelerates the development of fouling on heat exchange coil surface.

Water flow rate. Water flow rate has an important effect on development of fouling. Water can develop different scouring force on fouling at different flow rate. At fast water flow rate, water can scour fouling strongly, and then it will reduce fouling. Conversely, at low water flow rate, scouring force is smaller, and then it will be in favour of fouling[5].

In addition, from running status, the amount of 1# tower is smaller than 2# and 3# under the same quality of raw water, and that does not affect the normal operation of the system. So, the quality of raw water is not discussed in this paper.

Analysis of scaling difference

Scaling difference in pipes. Scaling difference in pipes mainly refers to scaling in spray pipelines(spray water is outside cooling water). In valve cooling system of Tianshengqiao converter station, the three spray pumps are unified in the pump pit, and then the distance of pumps and spray towers is different, in other words, the length of spray pipelines is different. While at early time of equipment operation, the flow rate of spray water is uniform, that is to say, water pressure in the valve outlet is uniform. Figure 1(a) show the simulated diagram of outside cooling water system of Tianshengqiao converter station. If the inner wall of the pipe surface is clear, and specific frictional resistance of pipe is 0.69KPa/m, and the difference of pipeline length is 10m, then the difference of

resistance caused by pipeline length is about 0.07bar, that is, 3# spray water pipeline resistance is greater than 1# spray water pipeline resistance 0.07bar. According to the theory of effect of pressure on scaling, precipitation of $CaCO_3$ will increase when pressure drops. Therefore, 3# spray water pipes have the most fouling, and 2# spray water pipes are second, and 1# spray water pipes have the least fouling. The actual operating conditions are consistent with the analysis.
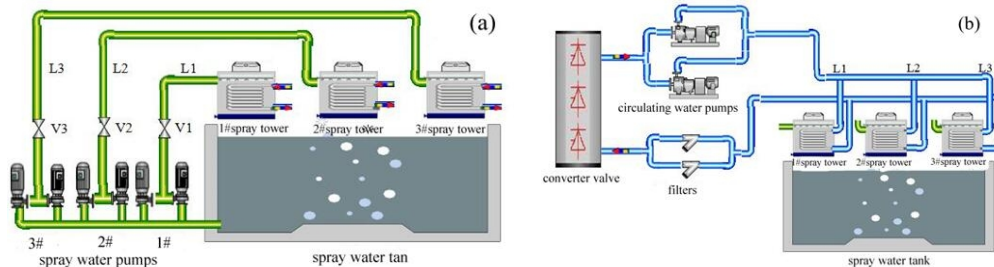

Fig.1 Simulated diagram of outside (a) and inside (b) cooling water system
of Tianshengqiao converter station

Scaling difference on heat exchange coil surface. (1) Inside cooling water flow. Under the condition of spray water flow consistent, inside cooling water flow is different, and then evaporation of spray water is bound to be different, consequently scaling difference on heat exchange coil surface is developed. According to formula of water heat transfer $P=\Delta t \times C \times Q$ (where P is heat dissipated power, Δt is water temperature difference, C is the specific heat of water, Q is flow of water), under the condition of invariable heat dissipated power, Δt will drop when Q increased, and the outlet water temperature become higher. And that, the temperature of heat exchange coil surface increases. Figure 1(a) show the simulated diagram of inside cooling water system of Tianshengqiao converter station. The length order of inside cooling water pipelines is L3>L2>L1. And then inside cooling water flow order is 1#>2#>3# because of existence of resistance, as a result, the temperature order of heat exchange coil surface is 1#>2#>3#. According to theory of effect of water temperature on scaling, the higher temperature, the more easy to scale. So, scaling on heat exchange coil surface of 1# tower is the minimal and 3# tower is the most in theory. But the theoretical results do not tally with the actual situation, this shows that inside cooling water flow is not the factors that cause scaling difference. (2) Spray water flow. Keep inside cooling water flow consistent, if spray water flow is different, then evaporation of spray water is different. Spray water flow is too high, that will reduce the cooling tower efficiency, as a result the temperature of spray water will rise, decomposition of $Ca(HCO_3)_2$ will be accelerated. The end result is accelerated scaling. On the contrary, spray water flow is too low, that will increase concentration ratio of spray water, speed up the scale. Therefore, there is a best value for spray water flow. And fouling on coil surface will keep minimum at the best value. The best value needs to be determined by experiments.

Experiment part

Experimental equipments

Field device cannot meet the experiment precision and operation requirements. The valve cooling system device has been used for years, and pipe and fitting parts have been corroded. What's more, the spray tower need to be stopped at any time to test in the experimental process. Field devices are vast and lack of necessary monitoring instrument, and cost is too high if making

field experiments. So it's not suitable for carrying out experiments at field devices. In this paper, the experimental devices are designed.

Heat dissipated power of field device decreases 189 times to design this experiment equipments. Experiment equipment includes three cooling tower, cooling power of each tower is 5kW. Simulation system employs 15kW heater to simulate the heat valve, and the heater power can be realized all power value from 1kW to 15kW. The inlet temperature of inside water is designed at 45-60°C, outlet temperature of inside water is designed at 40-55°C, the difference of inlet temperature and outlet temperature is designed 5°C. Experiment equipment has the same function with field valve cooling device, and it is based on the structure of original valve cooling system to reduce about 200 times, and it has advantage of easy maintenance and timely monitoring. It is highly targeted on scaling difference phenomenon of Tianshengqiao converter station. Experimental heat exchange coil configuration consistent with the field, and the coil is designed to detachable coil in order to analyze fouling status expediently. Spray pipelines are equipped with limited current circle in order to simulate the influence of pipe resistance on scaling. This experiment uses automatic operation simulative system, making the experiment more accurate control.

Experimental method

According to theoretical analysis and field situation of scaling difference phenomenon, Experiment carried out from three parts, that is inside cooling water flow, spray water flow and pipe resistance simulate experiment.

Inside cooling water experiment. Spray water flow keeps 10L/min by limited current circles through experimental process, and inside cooling water flow is a variable, changes from 2L/min to 18L/min. Clearing the heat exchange coil and drying it, then weighing it, keeping its weight, then loading it in cooling tower. Opening cooling system, and setting up it running automatically. Then starting the main circulation pump and adjusting valves to get expected inside cooling water flow. Opening heater and cooling tower fan, and setting temperature of inside cooling water is 40°C and targeted temperature of spray water is 35°C. After running 7 days, stopping equipment and removing heat exchange coil to observe the scale, weighing heat exchange coil and scale, keeping their weight. Changing inside cooling water flow and heat exchange coil, starting experiment again. Finally drawing curve of inside cooling water flow and amount of scale.

Spray water flow experiment. Keeping inside cooling water flow as a fixed value and spray water flow as a variable changing from 2L/min to 12L/min through experimental process. Clearing the heat exchange coil and drying it, then weighing it, keeping its weight, then loading it in cooling tower. Opening cooling system, and setting up it running automatically. Then starting the main circulation pump, and adjusting pipes valve to make inside cooling water flow is 10L/min. Opening heater and cooling tower fan, and setting temperature of inside cooling water is 40°C and targeted temperature of spray water is 35°C. Adjusting spray water pump outlet valve to make spray water flow reached the set value. After running 7 days, stopping equipment and removing heat exchange coil to observe the scale, weighing heat exchange coil and scale, keeping their weight. Changing spray water flow and heat exchange coil, starting experiment again. Finally drawing curve of spray water flow and amount of scale.

Pipe resistance simulate experiment. Keeping inside cooling water flow and spray water flow as a fixed value, and using limited current circles to simulate pipe resistance, which is a variable. Clearing the limited current circle and drying it, then weighing it, keeping its weight, then loading it on spray water pipeline. Opening cooling system, and setting up it running automatically. Then starting the main circulation pump, and adjusting pipe valves to make inside cooling water flow is 10L/min and spray water flow is 8L/min. Adjusting limited current circle to make pressure drop

achieve the set value. Opening heater and cooling tower fan. After running 7 days, stopping equipment and removing limited current circle to observe the scale, weighing limited current circle and scale, keeping their weight. Changing limited current circle, and starting experiment again. Finally drawing curve of pipe resistance and amount of scale.

Result and discussion

Figure 2 are curves of amount of scale and inside cooling water flow (a), spray water flow (b), and pipe resistance (c). It can be seen from figure2(a), coil surface scaling has increasing rend along with rising of inside cooling water flow. Because increase of inside cooling water will lead to increase of spray water temperature, and then coil temperature will be higher and higher. According to above theory analysis, the higher temperature, the more easy to scale. From figure 2(b) we can see that influence of spray water flow on scaling is complex, amount of scale decreases along with increase of spray water flow in small flow rang, then it increases when spray water flow continues to increase. On the one hand, spray water flow will affect heat exchange efficiency of cooling tower, on the other hand, it will affect instantaneous concentration ratio of spray water on coil surface. The former exists the best value at highest exchange efficiency. And concentration ratio will decrease with increase of flow. So there is a best value for spray water flow. From figure 2(c) we can see that amount of scale on limited current circles has a tendency to decrease with increase of pressure difference. The greater pressure difference, the stronger scour developed by water on pipe wall, and then the more unfavorable to scale. What's more, low pressure is beneficial to scale.
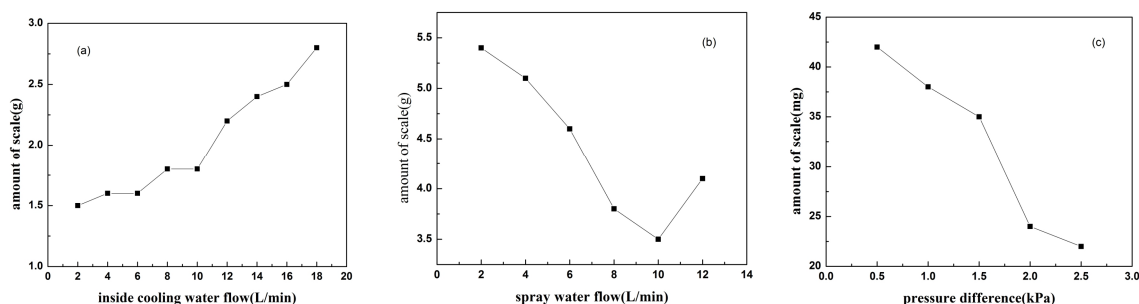

Fig. 2 Curves of amount of scale and inside cooling water flow (a),
spray water flow (b), and pipe resistance (c)

It can be seen from experimental results that inside cooling water flow is not the main factor for influent scaling, spray water flow and pressure difference are main factors. Pressure difference comes from pipe resistance. Spray water flow difference comes from length difference of spray water pipeline. The longer spray water pipeline, the smaller pressure at later pipeline, and the more easy to scale at later pipeline. That will lead to pipe scaling difference for long-term running, and then leading to difference in spray water flow. The result is a vicious circle.

Above all, the reason for scaling difference in Tianshengqiao converter station is length difference of spray water pipeline. In device running early days, length difference of spray water pipeline leads to scaling difference on pipe wall, and funning after a period of time, spray water flow gradually occurs difference with accumulation of time. Eventually scaling difference on heat exchange coil surface gradually happened.

Control strategy

Inside cooling water system.

The original inside cooling system divides into three branches, and their pipeline length is different. So inside cooling water flow is different at the same outlet pressure of pump, which inevitably leads to scaling difference. In order to reduce these differences, we can install valves in branches to control inside cooling water flow identical in each branch, as shown in figure 3(a). That will avoid scaling difference on coil surface.
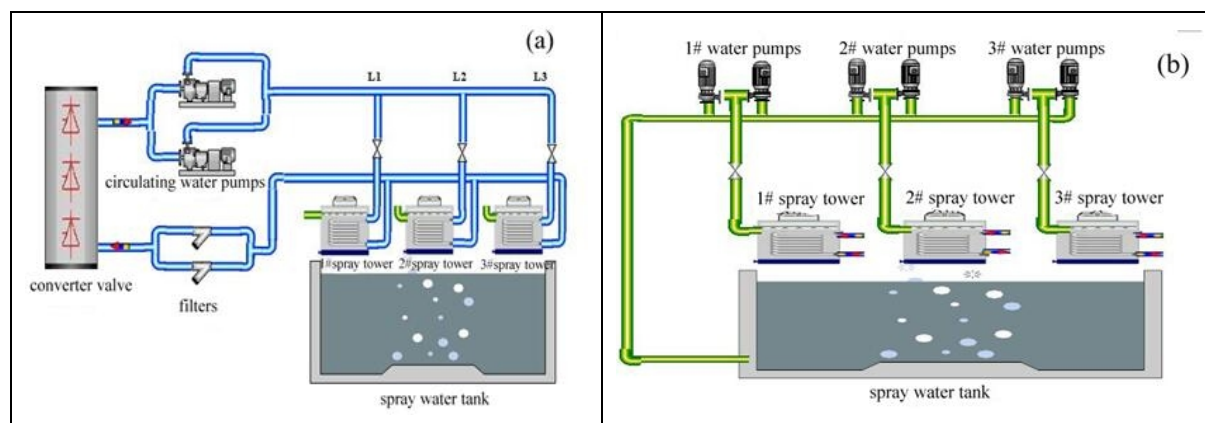

Fig. 3 Simulation diagram of inside cooling system(a) and
cooling tower and pump pit layout(b) in improving plan

Spray water system

There are two kinds of improving plans for spray water system, respectively aiming at new converter station and existing converter station. For new converter station, we propose that arrangement of cooling tower and pump pit adopts parallel way, so that pipeline length of spray water is consistent, as shown in figure 3(b). For existing converter station, we recommend to replace spray water pump to reduce flow difference of spray water flow in three branches. The method of selecting pump does not discuss in this paper.

We choose the plan of changing spray water pump for Tianshengqiao converter station. Spray water flow in Tianshengqiao converter station is $40m^3/h$, and pressure head of spray water pump is10m. we choose water pumps whose flow increase not less than 5% under the same head to replace 2# and 3# spray water pump. System runs for a year after improvement, amount of scale decreases significantly on heat exchange coil surface of 2# and 3# cooling tower. And thickness of scale sample of 1#, 2# and 3# tower respectively are 0.60mm, 0.75mm and 0.90mm. This shows that scaling difference of the three cooling tower disappeared. Quantity of scaling of the three cooling tower does not affect normal operation of system. Improvement effect is good and it has achieve expected goals.

Conclusion

We analysis the scaling difference phenomenon of valve cooling system in Tianshengqiao converter station, and determine the effect factors of this phenomenon. Scaling difference on heat exchange coil surface is caused by inside cooling water flow difference, spray water flow difference and pipe resistance difference. Large inside cooling water flow leads to high temperature of spray water, that accelerates decomposition of $Ca(HCO_3)_2$ and reduce solubility of $CaCO_3$, and then it accelerates development of scaling. From theoretical analysis we can conclude that spray water flow difference is the main factor of scaling difference of heat exchange coil surface. Experimental

result show that length difference of spray water pipeline leads to scaling on pipeline, that enlarges flow difference of spray water, and eventually scaling difference on cooling coil surface is developed. Control strategy is adding valves on inside cooling water pipeline and replacing spray water pumps. After improvement, scaling difference phenomenon on valve cooling system disappear, this shows that improvement effect is good. This method has great advantages in the aspects of economy and environmental protection, compared with softening and dosing treatment and other traditional anti-scaling technologies.

Reference

[1] Zhenyu Yang, Chengyi Yu: East China Electric Power Vol. 38 (2010), p. 369.

[2] Fang Liu, Guizhi Zhang, Lu Xia: CHEMICAL INDUSTRY AND ENGINEERING PROGRESS Vol. 29 (2010), p. 772.

[3] Qiang Gao, Lingfeng Zhang, Chenguang Li: Industrial Water Treatment Vol. 31 (2011), p. 20.

[4] Jia Wang, Yimei Tian, Hao Guo, Li Wang: Water & Westewater Engineering Vol. 38 (2012), p. 160.

[5] Jiangtao Hao: SOUTHERN POWER SYSTEM TECHNOLOGY Vol. 4 (2010), p. 99.