

Research on the Feasibility of the Self-circulating Evaporative Cooling System with Composites Structure for High Power Rectifier Equipment

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Abstract. Self-circulating evaporative cooling system is safe, effective and energy-saving. It has advantages compared with the traditional cooling technology. So it provides a new cooling method for high power rectifier equipment. Then take an example of the three-phase bridge full-controlled rectifier, a new cooling system with composite structure and non-single heat loads was proposed. Through analysis on the circulation mechanism and operation characteristics, the feasibility of the self-circulating evaporative cooling system which is composed of horizontal and vertical hollow conductor was studied in this paper.

1. Introduction

Evaporative cooling technology utilizes the latent of coolant to take away the heat loss. Compared with the traditional cooling method, it has advantage of high-efficiency, high reliability and stability. So it has been successfully applied to hydro generators, wind power generators and other electrical equipment.

The high power rectifier equipment mainly used as DC power supply in electrolysis plant for aluminium, copper, salt and etc. The cooling technology for high power rectifier equipment mainly includes water cooling and forced air cooling at present. However, following the capacity of high power rectifier equipment were developed to become larger than before, the cooling system for high power rectifier equipment is moving towards greater reliance on the safety and stability. The evaporative cooling technology provide a new method to solve the cooling problem. And different from water cooling and forced air cooling which need a pump to provide the circulate power, the self-circulating evaporative cooling system is no need for external power. The difference of density between liquid and gas coolant provides the driving force, so compared with the traditional cooling method, the self-circulating evaporative cooling system is energy-saving. So a self-circulating evaporative cooling system for high power rectifier was proposed in this paper.

However, the new system is not similar to the evaporative cooling system in previous study. The evaporative cooling system for hydro generator is composed with parallel vertical hollow conductors, the evaporative cooling system for turbine generator is composed with parallel horizontal hollow conductors. The hollow conductors with single structure all run at the same heat. But the high power rectifier equipment provides a system with composite structure.

In the evaporative cooling system proposed here, the thyristor and quick fuse are both cooled double-sided via the hollow conductors, which are filled with coolant. The hollow copper bus for parallel thyristor and quick fuse are vertical, and the hollow connection bus between thyristor and quick fuse are horizontal. And when the rectifier equipment is working, the heat load of vertical and horizontal hollow



conductors are different. Therefore the feasibility of the self-circulating evaporative cooling system with composite structure for high power rectifier equipment need to analyze and discussed. Then it is studied in this paper based the theoretical analysis on the circulation mechanism and operation characteristics.

2. Theoretical mode

The self-circulating evaporative cooling system for high power rectifier equipment is composed with condenser, gas up-collective tube, liquid sub-collective tube, liquid-down tube, hollow conductors and other connecting devices. Take an example of three-phase bridge full-controlled rectifier, the evaporative cooling system is shown in Fig1. In order to show the structure more clearly, only one of the three horizontal circulating channels for connection bus is shown here, and the other channels for connection bus between thyristor and quick fuse are the same.

As is shown in fig1, the coolant flows in the horizontal and vertical hollow conductors. When the rectifier is working, the coolant absorb the heat mainly generated by thyristor and quick fuse. Then the liquid coolant turns into gas-liquid phase. The two-phase coolant flows into condenser through gas up-collective tube and changes to liquid phase through heat exchange with the second cooling medium, such as air, or water. Then liquid coolant flow back through liquid-down tube. It flow into each horizontal and vertical hollow conductor through liquid sub-collective tube. Then the next circulation begin, and form a self-circulating without pump. The difference of density between coolant in flowing-up tube and flowing-down tube provides the driving force for circulation.

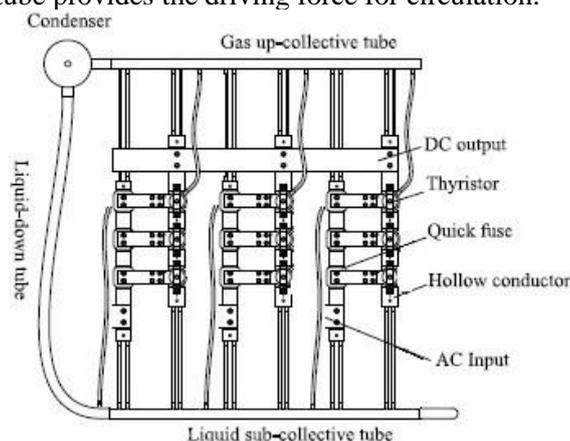


Fig.1. the configuration of the evaporative cooling system

As is shown in Fig1, the composite system is composed with many horizontal and vertical hollow conductors. In this paper, the minimum parallel unit was proposed, and then theoretical model was built for it. The structure of the minimum parallel unit is shown in Fig2.

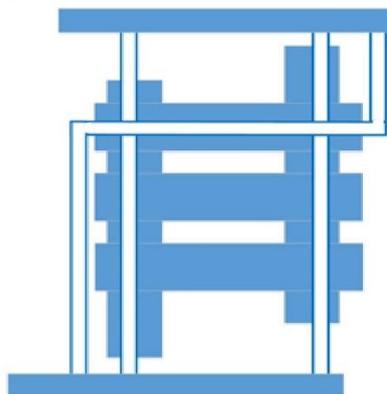


Fig.2. the structure of the minimum parallel unit

3. Nonlinear analysis

As a typical nonlinear dynamic system, the self-circulating system evolving phase transition is an instability system which has many variables and strong coupling. The state of the coolant flow in the self-circulating evaporative cooling system depends on the balance relationship between the flow resistance and driving force of circulation loop. Then the equations for the minimum parallel unit are established.

Assuming the condenser has enough capacity to ensure the temperature of coolant at entrance at a certain value, the driving force of the vertical hollow conductor for quick fuse and thyristor can be described as:

$$P_{drive-n} = \rho_{in} \cdot g(L_n + L_{out-n}) - \overline{\rho}_{l-n} \cdot gL_{l-n} - \overline{\rho}_{tp-n} \cdot gL_{th-n} - \rho_{out-n} \cdot gL_{out-n} \quad (1)$$

And the flow resistance of the vertical hollow conductor can be described as:

$$P_{resistance-n} = \Delta P_{lsc-n} + \Delta P_{in-n} + \Delta P_n + \Delta P_{out-n} + \Delta P_{guc-n} \quad (2)$$

If the vertical hollow conductor for quick fuse and thyristor are called loop-1 and loop-2, and n in above formula denote the two hollow conductor.

Then, if the horizontal hollow conductor for the connection conductor between thyristor and quick fuse is called loop-3, the driving force of the horizontal hollow conductor can be described as:

$$P_{drive-3} = \rho_{in} \cdot gL_{out-3} - \rho_{out-3} \cdot gL_{out-3} \quad (3)$$

And the flow resistance of the horizontal hollow conductor can be described as:

$$P_{resistance-3} = \Delta P_{lsc-3} + \Delta P_{in-3} + \Delta P_3 + \Delta P_{out-3} + \Delta P_{guc-3} \quad (4)$$

Here L_{lsc-n} denotes the length of loop-n in liquid sub-collective tube, L_{in-n} denotes the distance between the entrance of liquid sub-collective tube and the exit of the hollow conductor of loop-n. L_{l-n} denotes the length of single liquid phase section of the hollow conductor of loop-n, L_{tp-n} denotes the length of two-phase section of the hollow conductor of loop-n, L_{out-n} denotes the distance between the exit of hollow conductor of loop-n and gas up-collective tube. L_{guc-n} denotes the length of loop-n in gas up-collective tube. In the equation above, the homogeneous theoretical model of two-phase flow was chosen to calculate the resistance pressure drop.

In the self-circulating system, according to the balance relationship the fundamental equation can be shown as:

$$P_{drive} = P_{resistance} \quad (5)$$

Based on the heat balance, the following formulas can be got.

$$H_{s-(P_n-\Delta P_{l-n})} = H_{in-n} + \frac{Q_n}{m_n} \frac{L_{l-n}}{L_n} \quad (6)$$

H_{in-n} denotes the enthalpy at the inlet of hollow conductor of loop-n. The left of equation (4) denotes the saturated enthalpy at the pressure which is $P_{in} - \Delta P_{l-n}$.

Then the mass quality of gas phase at the outlet of the hollow conductor of loop-n can be described as:

$$x_{e-n} = \frac{Q_n}{m_n R} \frac{L_{tp-n}}{L_n} \quad (7)$$

In this paper, based on the non-linear analysis theory, the arc-length continuation method was chosen.

$$\begin{cases} F_n(m_n, Q_n) = 0 & (n = 1, 2, 3) \\ B(m_n, Q_n, s) = 0 \end{cases} \quad (8)$$

Then the evolution curve of the equilibrium state of the loop-1, loop-2 and loop-3 in the self-circulating evaporative cooling system can be got.

4. Conclusion

The evolution curve of equilibrium state of the minimum parallel unit is shown in Fig.3.

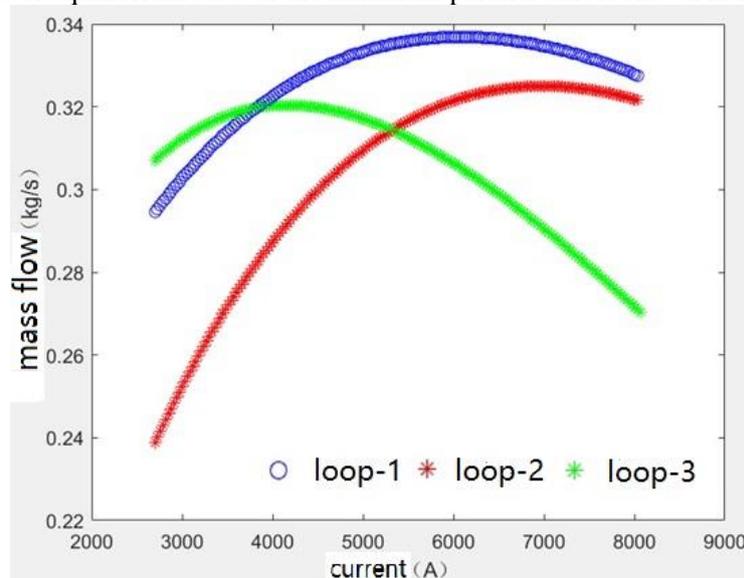


Fig.3. the evolution curve of equilibrium state of the loop-1, loop-2 and loop-3

As is shown in Fig3, in the system with two vertical hollow conductors and one horizontal hollow conductor, the three loop all show different characteristics from which of single loop. And through reasonable design the bifurcation will not occur in the self-circulating system with three parallel hollow conductors with different structure and heat load. The impact on cooling system caused by sudden change of flow rate can be effectively avoided. So the parallel system with composite structure and different heat load can accomplish the cooling goal without pump. The analysis results show the feasibility.

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References

- [1] Xu Jijun. "The Boiling Heat Transfer and Vapor-Liquid Two Phase Flow," Beijing: Tsinghua University Press, 2002, pp.205-207.
- [2] Boure J.A., Bergles A.E., Tong L.S. Review of two-phase flow instability. Nuclear Engineering and Design, 1973, 25:165-192.
- [3] Yao Wei. "Experimental and theoretical research on the instability mechanism of boiling two-phase natural circulation system", dissertation for the doctor degree of Shanghai Jiaotong University, 2000, 08.
- [4] Ruan Lin. The Basic Theory Research of the Inner Evaporative Cooling System for the Large Hydro-generator and the Simulation of the CLSC system. dissertation for the doctor degree of Chinese academy of sciences. 2004.06.
- [5] Yan Jing. Study on the Two-phase Flow Frictional Pressure Drop and Instability of the Evaporative Inner Cooling System for Wind Power Generator, dissertation for the doctor degree of Chinese academy of sciences. 2013.06.
- [6] Cai Jing, Study on the Friction Resistant in the Hollow Stator Bar of Evaporative Cooling Generator, dissertation for the doctor degree of Chinese academy of sciences. 2005.06.

- [7] R. Mosdorf, Ping Cheng, H.Y. Wu, M. Shoji. Non-linear analyses of flow boiling in microchannels. *International Journal of Heat and Mass Transfer*, 2005, 48:4667-4683.
- [8] Jianhui Xie, R.S. Amino. Numerical simulation of two-phase flow in microchannel. 2004 Inter Society Conference on Thermal Phenomena, 679-686. Eason, B. Noble, and I. N. Sneddon, "On certain integrals of Lipschitz-Hankel type involving products of Bessel functions," *Phil. Trans. Roy. Soc. London*, vol. A247, pp. 529-551, April 1955. (references)
- [9] J. Clerk Maxwell, *A Treatise on Electricity and Magnetism*, 3rd ed., vol. 2. Oxford: Clarendon, 1892, pp.68-73.
- [10] I. S. Jacobs and C. P. Bean, "Fine particles, thin films and exchange anisotropy," in *Magnetism*, vol. III, G. T. Rado and H. Suhl, Eds. New York: Academic, 1963, pp. 271-350.
- [11] K. Elissa, "Title of paper if known," unpublished.
- [12] R. Nicole, "Title of paper with only first word capitalized," *J. Name Stand. Abbrev.*, in press.
- [13] Y. Yorozu, M. Hirano, K. Oka, and Y. Tagawa, "Electron spectroscopy studies on magneto-optical media and plastic substrate interface," *IEEE Transl. J. Magn. Japan*, vol. 2, pp. 740-741, August 1987 [Digests 9th Annual Conf. Magnetics Japan, p. 301, 1982].
- [14] M. Young, *The Technical Writer's Handbook*. Mill Valley, CA: University Science, 1989.