Practice of Excitation Room Ventilation and Cooling Modification in a Nuclear Power Plant

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Abstract. Excitation equipment is critical to nuclear power plants. To ensure reliable operation of excitation equipment is very important for generation reliability. Some shortcomings appear in the excitation room ventilation and cooling system, which cause uneven temperature and hot points in the excitation room. High temperature of inlet air challenges excitation equipment. An external circulating modification is performed, which makes up the shortcomings of original ventilation and cooling system. This paper describes characteristic of excitation equipment, shortcomings of original ventilation and cooling system, modification plan and its effects.

Keywords: Nuclear Power Plant; Excitation Room; Rectifier Cabinet; Ventilation and Cooling Modification; External Circulating.

1. Introduction
Excitation equipment is critical to the station, identified as SPV equipment (single point vulnerability, which will cause large power generation loss to the power plant). Excitation cabinet rectifier bridge generates a large amount of heat during operation. If it cannot be effectively cooled, the temperature of the rectifier bridge will exceed the tripping set value. The excitation cabinet is placed in the Excitation Room of the conventional island, the original ventilation and cooling system of which are less effective, and the heat dissipation of the equipment cannot be effectively exported. The external circulation is used in this modification, which successfully solves the existing problems.

2. Introduction to excitation cabinet
In normal operation, the heat of the excitation cabinet mainly comes from the heating of the components of the rectifier cabinet and the heat of the excitation isolated bus that enters the cabinet through the EA cabinet. According to the data provided by the manufacturer, the maximum heat dissipation of the excitation system is 90kW under the long-term rated operation condition of 1.1. The air inlet of the rectifier cabinet is equipped with temperature monitoring components, which will alarm and trip when the set value is exceeded.

The station is equipped with 6 sets of rectifier cabinets (N-1 configuration), each of which is equipped with a cooling fan for forced convection cooling of the internal components of the rectifier cabinet. The suction air outlet of the cooling fan (shown in the green line segment in Figure 1) is located on the front of the rectifier cabinet, and the exhaust air outlet (shown in the blue rectangle in Figure 1) is located on the upper part, and reaches the back of the rectifier cabinet. In order to solve the practical problems of...
the station, the station focuses on the optimization and improvement of the cooling system in the Excitation Room, which is also the main content of this paper.

3. Design of Primary Cooling System for Exciter

The excitation cabinet is arranged in the Excitation Room of the turbine building of our station. In the original design, three separate air conditioners A/B/C were arranged in the excitation room for room cooling to ensure the operating environment of the excitation cabinet. Two of them are arranged on the front of the excitation cabinet, and one is arranged on the side of the excitation cabinet, as shown in Figure 1.

![Figure 1. Schematic diagram of original ventilation and cooling design](image)

3.1. Existing Problems

After entering the high-power operation platform, it was found that the temperature distribution in the excitation room was not uniform. Eight points in the excitation room were selected for temperature measurement (as shown in the figure2), and the data were as follows:

| Spots | Temperature (°C) |
|-------|------------------|
| Point1 | 28               |
| Point2 | 24.7             |
| Point3 | 24               |
| Point4 | 20.8             |
| Point5 | 30.7             |
| Point6 | 29.3             |
| Point7 | 22.9             |
| Point8 | 22.1             |

As can be seen from the table above, the front of the excitation cabinet has a temperature gradient of 7.2°C from left to right, and the back has a temperature gradient of 8.6°C. Points 1 and 5 are the two hot spots in the room. As Point 1 is one of the cooling suction outlets inside the rectifier cabinet, the inlet temperature of the leftmost No.6 rectifier cabinet is high. According to Newton's cooling formula: \( \phi = h(A(t_w - t_f)) \), the convection heat transfer of heat flow \( \Phi \) is proportional to the size of the heat transfer.
surface area \( A \) and the temperature difference between solid wall and fluid one \( (t_w - t_f) \). Hence, the high temperature of rectifying tank inlet \( t_f \) causes the decrease of cooling, affecting the safe and stable operation of the rectifier cabinet.

According to on-site inspection and analysis, the reasons for the high temperature gradient and hot spots in the room are as follows:

1) The location of air conditioner is unreasonable. The heating parts of the excitation cabinet are mainly on the left side of the room, but the arrangement of the air conditioner is to the right. As there are wall columns on the left side of the air conditioner A (as shown in Figure 1), it is impossible to send the cold air to the inlet on the left side of the excitation cabinet by adjusting the air outlet guide blade.

2) The air inlet and outlet of air conditioner A/B are all located in the front of the excitation cabinets—the outlet is on the top, and the inlet is on the bottom. Due to the fact that the height of the air supply outlet and the excitation cabinet are basically the same, the cold air from the air supply outlet is blocked by the cabinet and returns to the suction outlet, forming a short circuit and resulting in poor cooling efficiency of the air conditioner. Although the overall temperature of the room is high, the A/B refrigerant compressor of the air conditioner does not run continuously. Even though the cooling capacity of a single air conditioner is 54KW and the two air conditioners can meet the requirement of heat dissipation of 90KW from the point of the cooling capacity, due to the short circuit of air conditioning/suction outlet, even if three air conditioners run at the same time, the temperature gradient of the room is still relatively obvious.

![Figure 3. Circulation diagram of cabinet type split air conditioning in a room](image)

3) The exhaust outlet of the excitation cabinet is on the back, and the heat is mainly concentrated there. And the hot air on the back can not be returned to the suction of the air conditioner because the air suction capacity of the air conditioner fan is limited. At the same time, the pressure \( P_5 \) at the point 5 on the back of the excitation cabinet is greater than the pressure \( P_1 \) at the point 1 on the front, causing that the hot air on the back spreads to the cooling suction of excitation cabinet through the gap between the left side of the excitation cabinet and the wall.

![Fig. 4 Schematic diagram of convection between the front and rear of excitation cabinet](image)
3.2. Temporary Measures and Effectiveness

3.2.1. Temporary Measures. After abnormalities occur, the following temporary measures are mainly taken to deal with them:

1) Adjusting the direction of air supply guide vane of air conditioner. Air supply is arranged as far as possible towards the top, to avoid the formation of short circuit. At the same time, the cold air of air conditioner A is blown to the inlet of the excitation cabinet.

2) A temporary fan is added on the back of the excitation cabinet to circulate the hot air to the B/C suction of the air conditioner, so as to improve the refrigeration efficiency of the air conditioner.

3) Adding temporary fan on front of cabinet, and making sure that the air direction is from right to left. Since the room temperature is higher on the left side and lower on the right side, the fan can send cold air from the right to the left. In the mean time, the air pressure of the left inlet of the excitation cabinet can be increased to prevent the hot air on the back from diffusing to the front.

![Figure 5. Schematic diagram of interim measures](image)

3.2.2. Effectiveness. After the temporary measures were added, temperature measurements were made for points 1-8 in the room. The results are as follows:

| Parameters | Before the measures (℃) | After the measures (℃) |
|------------|-------------------------|------------------------|
| Point1     | 28                      | 26.9                   |
| Point1     | 24.7                    | 23.2                   |
| Point1     | 24                      | 22.3                   |
| Point1     | 20.8                    | 21.2                   |
| Point1     | 30.7                    | 33.4                   |
| Point1     | 29.3                    | 31.2                   |
| Point1     | 22.9                    | 25.7                   |
| Point1     | 22.1                    | 26.0                   |

After the addition of temporary measures, the temperature gradient of the room was significantly improved, that the temperature gradient in the front of the cabinet decreased from 7.2℃ to 5.7℃, and the back’s decreased from 8.6℃ to 6.6℃, due to the enhancement of air circulation. However, the overall temperature of the room did not decrease significantly.

4. Modification Scheme

The effectiveness of temporary measures is limited and the stability is not high. For example, the temperature rise of rectifier cabinet was caused by the shutdown of the temporary fan due to the power connection falling off. In order to improve the operation reliability of the excitation cabinet, it is decided to carry out modification of the ventilation system. After research and demonstration, the scheme of using external circulation is determined, that is, the cooling equipment is placed outdoors, through the connection of the air duct, the cold air is sent to the front of the excitation cabinet air inlet and the back
of the excitation cabinet is provided with a return air duct, as a result, the hot air returns to the cooling equipment through the air duct. The advantages of this scheme are that the air circulation in the excitation room can be fully realized, the operating efficiency of cooling equipment can be improved and the air supply position is flexible, which can send the cold air to the desired position.

4.1. Cooling Equipment Selection

The most ideal cooling equipment is the combined air conditioning unit composed of fan, coil and filter, which has the advantages of strong cooling capacity, large air volume, strong control and display function and has the disadvantages of large volume, inconvenient installation, and the need to interface with the power plant chilled water system. Considering the difficulty of site layout, the combined air conditioning unit is not feasible. After investigation, a brand of split air conditioning can be connected to the air duct, the size of which meets the needs of site installation, the air conditioning is back to back up, the top is the air supply outlet of the air conditioning, the rear part of the return air outlet, and the air outlet can be connected to the air duct.

Due to the condition that the air duct is connected, the air conditioner needs to provide a certain amount of external residual pressure., which is required to be greater than or equal to 250Pa according to the calculation. The standard type of air conditioner provided by the manufacturer is 400Pa, which meets the design requirements. The cooling capacity of air conditioning is consistent with the original.

4.2. Air supply pipe layout

When it comes to the selection of the location of outdoor air conditioning, the main consideration is to shorten the length of the air duct and reduce the difficulty of layout. Two new air conditioners are arranged near the outside of the right wall of the excitation room.

The air supply duct is connected with the outlet of the new air conditioner and enters the room through the roof of the excitation room. Four air supply outlets are arranged, among which three vertical air supply outlets (tuyere facing down) are located above the front face of the excitation cabinet, and one horizontal is located at the air inlet on the left side of the excitation cabinet. The air supply outlet is equipped with manual baffle, which can adjust the air volume.

According to the air speed required by the specification, the cross-sectional area of the roof air duct is 800*800, the cross-sectional area of the indoor air duct is 500*800, and the cross-sectional area of the indoor air supply outlet is 800*800.

4.3. Layout of Return Air Duct

As can be seen in the blue lines from figure3, the return air outlet is arranged on the back of the excitation cabinet to send the hot air in the room to the air conditioner suction, which is equipped with an electric damper to interlock with the air conditioner. The return air outlet is equipped with manual damper, which can adjust the air volume.

According to the air speed required by the specification, the cross-sectional area of the outdoor air duct is 800*630, the cross-sectional area of the indoor air duct is 500*800, and the cross-sectional area of the indoor return air outlet is 800*800.
5. Verification of Modification Effectiveness

5.1. Temperature

After the modification, the temperature of the excitation points 1-8 was measured and compared with the data before. The comparison results are shown in Table 1 below. It can be seen from the data:

1) The temperature gradient of the room in front of the excitation cabinet (point 1-4) decreases from 7.2°C to 1.2°C, and the temperature gradient of the room is not obvious after the modification. The temperature gradient of the room behind the excitation cabinet (point 5-8) decreased from 8.6°C to 5.8°C.

| Point  | Before modification (°C) | Point1 | Point2 | Point3 | Point4 |
|--------|--------------------------|--------|--------|--------|--------|
|        |                          | 28     | 24.7   | 24     | 2.8    |
|        | After modification (°C)  | 22.5   | 24.1   | 18.8   | 21.3   |
|        |                          | 30.7   | 29.3   | 22.9   | 22.1   |
|        | After modification (°C)  | 27.5   | 25.6   | 22.6   | 21.7   |

2) The average temperature of the room decreased from 25.3°C to 23°C after the modification. The temperature of the two hot spots (point 1 and point 5) in the room decreased, and the point 1 located at the excitation cabinet air suction changed significantly.

5.2. Inlet Air Temperature of Excitation Cabinet

The comparison of the inlet air temperature shown at the measuring points of the six rectifier cabinets before and after the modification is shown in Table 2, that the temperature has decreased significantly, among which the No.6 rectifier cabinet has decreased from 42°C to 36°C, which greatly improves the operation reliability of the excitation cabinet.

| Rectifier cabinet | Before modification (°C) | After modification (°C) |
|-------------------|--------------------------|-------------------------|
| 1                 | 28                       | 25                      |
| 2                 | 28                       | 25                      |
| 3                 | 30                       | 27                      |
| 4                 | 36                       | 31                      |
| 5                 | 38                       | 31                      |
| 6                 | 42                       | 36                      |

6. Conclusion

The ventilation modification of the excitation room modified the original indoor split air conditioner cooling into external circulation cooling, which improved the uneven distribution of indoor temperature and eliminated the hot spots in the room, finally decreasing the temperature of the rectifier cabinet and improving the operation reliability of the critical equipment.

Due to layout constraints during the current stage, the better performing combined ventilation unit cannot be used. The practice of the modification can be used as reference in the subsequent projects,
and the ventilation of the excitation room should be reasonably planned in the design, construction and installation stages.

References

[1] Seung-Hun Song, Jong-Rae Cho, Jin-Seong Park, Verification of structural integrity and cooling performance of DRCS cabinet in power plant, Advances in Mechanical Engineering, Volume 12, Issue 9, 2020.

[2] Michael Boles, Yunus Cengel, Thermodynamics: An Engineering Approach, 8th Edition, 2014-01-07.

[3] Meseret T. Kahlasy, Girma T. Bitsuamlak, Fitsum Tariku, Effect of window configurations on its convective heat transfer rate, Building and Environment, Volume 182, 2020.

[4] Georgios Mavromatidis, Kristina Orehounig, L. Andrew Bollinger, Marc Hohmann, Julien F. Marquant, Somil Miglani, Boran Morvaj, Portia Murray, Christoph Waibel, Danhong Wang, Jan Carmeliet, Ten questions concerning modeling of distributed multi-energy systems, Building and Environment, Volume 165, 2019.

[5] Irem Velibeyoglu, Hae Young Noh, Matteo Pozzi, Empirical investigation of regression models for predicting system behavior in air handling units, Science and Technology for the Built Environment, Volume 25, Issue 3, 2019, PP 247-260.