Research on Low Carbon and Energy Saving Technology Path of Nuclear Power HVAC System

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Abstract. Nuclear power is the most realistic choice to cope with climate change and low-carbon transformation of energy structure, and it is also the inevitable trend for China to achieve the "double carbon goal". At present, the design task of nuclear power HVAC is not only to meet the functional requirements of users, but also to fulfill the tasks of efficient use of resources, environmental protection, energy saving and emission reduction. This paper discusses several "low carbon" technology paths that can be researched, developed and selected in the design process, including cold storage, pipeline optimization, cooling heat recovery, cold and hot air distribution, etc., analyzes the main problems and applicable conditions, and provides reference suggestions for the sustainable development of HVAC design and operation of nuclear power in China.

Keywords: Nuclear power · Low-carbon · Nuclear HVAC · Cold storage · Pipeline optimization · Cooling heat recovery

1 Introduction

In the multi-wheel drive energy system of coal, oil, gas, electricity, nuclear, new energy and renewable energy, which has been formed in China. Nuclear power has high energy density, large single power, long-term stable operation, clean and efficient application for bearing the base load of large power grid and necessary peak shaving, and has outstanding advantages compared with other energy sources. It is the most realistic strategic choice for China to achieve the goal of "double carbon" and build a low-carbon energy system [1]. It is estimated that the installed capacity of nuclear power in China will account for more than 10% of the total power generation by 2030 and more than 20% by 2060. For the nuclear power industry, the future nuclear power engineering industries such as nuclear power design, construction and commissioning will face unprecedented opportunities and challenges.

Nuclear power plant can be regarded as a large-scale system with precise cooperation of multidisciplinary systems, and each "subsystem" has different operation modes and energy consumption modes. HVAC is also one of them, which consists of about 20 subsystems such as ventilation, air conditioning, smoke control and chilled water. In

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the past design work, subject to the application requirements of mature technologies, energy saving and low carbon are not important tasks of design procedure, but only whether the relevant Standard is achieved as a measure. In other industries, especially in the construction industry, the energy consumption of HVAC system is listed as the primary energy consumption in the operation stage, and the goals and measures of "green" and "low carbon" have been generally accepted and implemented [2], and the corresponding technologies tend to be mature and reliable. Based on the above situation and the wide application of HVAC system in nuclear power plants, this paper discusses several energy-saving technology paths that can be studied and selected in the design process, including cooling heat recovery, cold and hot air distribution, cold storage, etc., analyzes the applicable conditions and basic ideas, and provides reference suggestions for the "low carbon" idea in the design and operation stage of nuclear power HVAC.

2 Cooling Heat Recovery

The air conditioning system of the main control room is used to maintain the appropriate temperature and humidity in the habitable area of the main control room during the running state and accident condition of the plant, and provide suitable environmental conditions for the correct operation of equipment and personnel [3]. Ensure the habitability of the habitable area of the main control room in the event of radioactivity pollution incident in Yard. This system does not directly participate in the three major security functions of plant, but as a support system, it provides suitable operating environment conditions for the systems and equipment participating in the three major security functions of plant. In the existing nuclear power technology, the main control room of the nuclear island is equipped with the air conditioning system of the main control room. When the system is in normal operation, it is in the mode of fresh air plus primary return air and all air. The supplied air is uniformly treated by the air handling unit and then sent to the area to maintain the appropriate environmental conditions of temperature and humidity. After the air is cooled and dehumidified by the surface cooling section of the air handling unit (connected with the chilled water system serving the area), it needs secondary heating to reach the temperature and humidity of the supply air. At present, it is used by Electric heater, at the end of Duct. The heat dissipation of nuclear power plant equipment is large, and the air conditioning system in the main control room runs continuously all the year round. The above-mentioned methods have the situation that high-grade cold and heat sources cancel each other. Therefore, under the above conditions, the cooling water (minimum 15 °C and maximum 45 °C) corresponding to the refrigerator of the chilled water system can be recovered by adding a hot water Coil heating section in the air handling unit of the air conditioning system of the main control room; A connecting pipeline loop and an electric valve are added to the cooling water from the heating section of the hot water Coil to the refrigerator of the original main control room air conditioning system corresponding to the chilled water system, and part of the cooling water is introduced to heat and raise the air temperature after cooling and dehumidification by the surface cooler, so as to meet the air supply temperature and humidity required by the indoor environment. Its principle is shown in Fig. 1.

The method can realize the heat energy recovery and secondary utilization of the cooling water of the refrigerator, not only can reduce the electric heat energy consumption

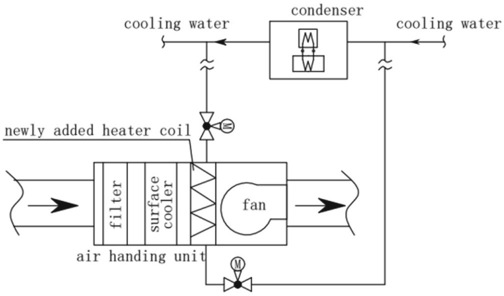

Fig. 1. Schematic diagram of cooling water heat recovery in main control room of nuclear island

of the heated air, but also can improve the refrigerant efficiency. The required pipeline modification is also easily coupled with the existing air conditioning and chilled water systems, with low economic cost, basically no influence on other systems and high practicability.

3 Hot and Cold Air Distribution

Most of the electrical instruments and equipment in the nuclear island plant are concentrated in the electrical room, control cabinet room, communication computer room command center and other rooms of the whole plant. All kinds of electrical cabinets, control cabinet and other electrical equipment have a large amount of heat dissipation, and the HVAC system mainly uses exhaust air to dissipate heat and has a large amount of ventilation. Take part of the ventilation [3]. At present, the air distribution scheme adopted by the electric instrument computer room served by the system is the way of side air supply and side air return, which is no different from other functional rooms.

This paper thinks that we can refer to the design mode of civil data center [4]. Consider establishing targeted air flow organization of sending and returning air, which can reduce the mixed flow of cold and hot air flow validity and improve the utilization rate of cold air and cold energy.

On this basis, the air distribution situation can be air supply and return under the overhead floor [5]. That is to say, the overhead floor is used as the static pressure box, and the cold air is sent out from the air supply outlet located in the cold channel in front of the cabinet, sucked by the fan in the Power supply of the cabinet, and then discharged into the hot channel after absorbing heat, and then entered the return (exhaust) air pipe located at the top to reciprocate. The air supply mode has the main advantage of less electric energy loss compared with the traditional mode in operation.

4 Cold Storage

In some large-scale air conditioning water systems, in order to achieve the function of continuous refrigeration, the main measures adopted are cold storage technology. It should be considered that the air conditioning system can still maintain normal operation when the power system supplied by the system has unexpected power failure. Therefore, it is necessary for the water system to configure cold storage tanks to store the cooling load needed by all systems in stable operation after switching from commercial power to diesel power. There are three kinds of cold storage media commonly used in engineering [6]. Water: The temperature change of water is used to store sensible heat. The cold storage temperature is generally above 4 °C, and the temperature difference of cold storage is 5–11 °C. The accumulated cooling capacity per unit volume of water is small, ranging from 5.8 to 12.77 kWh/m^3, and the volume of cold storage tank is large. The refrigerator can operate under conventional air conditioning conditions or slightly lower temperature. Ice: the latent heat of ice dissolution is used to store cold energy, and the ice making temperature is generally − 4 to − 8 °C; The storage capacity of ice is 40–50 kWh/m^3, and the storage capacity of ice storage tank is smaller than that of water storage tank. Ice storage can provide lower water supply temperature, which is suitable for air conditioning projects with large temperature difference and low temperature water supply, low temperature air supply, regional cooling and unconditional design of water storage. However, at least one refrigerator is of double working conditions, and its efficiency will decrease during ice making. Eutectic salt: The mixture of inorganic salt and water is called eutectic salt, and the phase transition temperature of eutectic salt is generally 5–7 °C. The storage capacity is about 20.8 kWh/m^3, and the volume of storage tank is between ice storage and water storage. The refrigerator can operate under conventional air conditioning conditions, but the maturity and reliability of eutectic salt materials need to be tested by time.

Water cold storage is a cold storage mode with the smallest accumulated cold capacity per unit, which requires the largest volume of cold storage tank. However, water cold storage does not need double-working refrigeration units, and does not need special cold storage forms commonly used in refrigeration and mass interception centers. It is well combined with the original conventional chilled water system. At present, cold water storage tanks are used in chilled water systems of nuclear power plants in recent years. For example, the operating chilled water system of a nuclear power plant in is equipped with four large-capacity main chilled water production columns [3], each column consists of a chiller and a Circulating Water Pump, one of which is standby. Considering the low-load operation in winter, another cold storage tank is set to avoid the low-load operation of large-capacity cooler. A bypass Regulating pipeline is set between the main water supply and return pipes of the system, so as to ensure the constant flow of cold water through the chiller when the flow rate of users changes. Two expansion constant pressure tanks are used for constant pressure. According to the demand of ventilation system, the system determines the number of coolers and corresponding pumps put into operation. The cold storage tank is used to improve the thermal inertia of the system, and avoid the frequent start-up and stop of the cold water cooler caused by the low cooling load of the users served by the system under the working condition of “complete discharge of the reactor in winter”, and the continuous cooling capacity of the chilled water system in Guaranty under the condition of short-term power loss. However, there are many problems in this scheme at present. Due to the large heat dissipation of various process equipment pipelines on the nuclear island, and nuclear power safety considerations, the safety margin is high, the system capacity is set according to the maximum, and the main equipment of the system (including water chillers, water storage tanks, water pumps, diaphragm constant pressure tanks, etc.) occupies a large area and space cost, which is not conducive to the optimal design of the nuclear island plant; In normal operation, chillers and corresponding pumps are easy to be in the low efficiency range of equipment, which not only causes a lot of energy waste, but also is an unfavorable factor for the maintenance of the equipment system itself; In the case of losing the Power supply outside the plant, the chilled water supply from the Guaranty of the electric refrigeration chiller caused the system equipment to occupy a large load on the emergency diesel engine; The operation chilled water service area is large, and the system water capacity is high. The system is equipped with water storage cold storage tanks, which further increases the system water capacity and increases the leakage risk and layout difficulty to a certain extent. The diaphragm type constant pressure tank designed by calculation is large in volume, and it is difficult to arrange it in the factory building.

In this paper, a scheme of ice-storage and cold-storage chilled water system for nuclear island operation is proposed for discussion. Two water-cooled electric chillers with a load capacity of 2 × 50% and corresponding water pumps are arranged in parallel in the system (the cooling water is taken from the nuclear island chilled water system); Set up two ice storage tanks with a capacity of 50% of the system load and supporting cold release facilities; Two water chillers and two cold storage tanks can be used as standby for each other; Set up one high-level expansion water tank; Set up corresponding pipelines, electric valves, Strainer, etc. to provide chilled water for the normal operation of nuclear island unsafe air conditioning and ventilation system and other systems requiring chilled water cooling source, to release cold from ice storage cold storage device in case of losing the Power supply of the plant, and to provide chilled water for users who need to operate under this working condition within a certain period of time. The schematic diagram of the scheme is shown in Fig. 2.

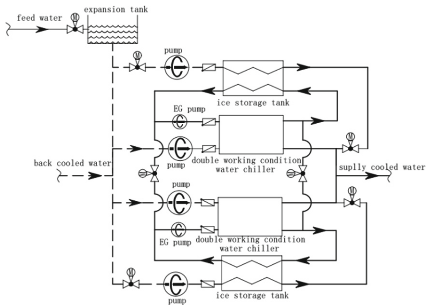

Fig. 2. Diagram of the scheme

Under the premise of safety redundancy, the scheme should set as few electric refrigeration chillers (capacity 2 × 50%), parallel ice storage tanks (2 × 50%) and supporting cold release facilities as possible to meet the functional requirements. The total occupied area of system equipment is reduced, which is beneficial to the optimization of plant layout; During normal operation, two chillers and two ice storage cold storage tanks can be used as standby for each other; The cold storage tank can also be used as a continuous and uninterrupted chilled water cooling source when the external power (LOOP) is lost, and only the cold release water pump loads the emergency diesel engine Power supply, which greatly reduces the corresponding emergency diesel engine load; During normal operation, the cold storage device can release the cold flow according to the end load Regulating, so as to take the total chilled water supply in Regulating and the Guaranty electric refrigeration chiller to operate in the high energy efficiency ratio range, which improves the operation efficiency and economy of the system; Because of the large water capacity of the system, the high-level expansion water tank of the system is selected for constant pressure, which is smaller than the diaphragm constant pressure tank and occupies a small area, and the constant pressure water replenishment effect is stable; Ice storage has small cold loss (2–3%), which is phase change storage. Compared with water storage, ice storage has small volume and saves land. The cold release end can realize closed system, and the energy consumption of water pump is also small, all of which achieve the goal of relative energy saving. Ice storage technology is widely used in civil construction industry in China, and its reliability and experience have been accumulated for a long time. It is also feasible to use it in non-safety system of nuclear island, which is worthy of in-depth discussion.

5 Conclusion

In this paper, three preliminary energy-saving schemes are put forward, including heat recovery of cooling water, application of air distribution in cold and hot channels and application of cold storage technology in chilled water system of nuclear island, and their application scenarios and feasibility are given. At the same time, the new scheme will always bring new problems.

The recovery and reuse of cooling water heat energy in the main control room area can not only reduce the electric heat energy consumption of heated air, but also improve the refrigerant efficiency. The required pipeline modification is easily coupled with the existing air conditioning and chilled water systems, which has low economic cost, basically has no influence on other systems and high practicability. However, due to the division of areas, the relevant pipelines can only be laid in this area, and the total energy recovered is low.

The air distribution method of air supply and return under the overhead floor makes the circulation of air supply and return in the electrical equipment room smoother, absorbs heat more accurately, saves a lot of energy consumption in ventilation system operation, and the selection of main equipment such as Fan in ventilation system configuration can also reduce the risk of "hot spots" of electrical equipment, which is helpful for equipment maintenance. The scheme is also feasible in plant equipment layout. But this scheme needs to increase a lot of interfaces with electrical equipment specialty, and it needs to increase the accuracy of design calculation, so as to save energy and not reduce the reliability of the system at the same time.

The scheme of ice storage nuclear island chilled water system applies the principle of phase change cold storage to the load Regulating of unsafe nuclear island chilled water system running continuously all year round, which not only reduces the initial investment cost and operation energy consumption of the system, but also makes the system cope with various load states. This scheme is quite different from the existing scheme, and there are still many problems to be further studied. Although some main equipments, such as double-working condition chillers, ice storage tanks and ethylene glycol solution pumps, are widely used in other industries, there is no reference experience in nuclear power plants. Therefore, research and Arguments also need time and accumulation, and need further study.

To sum up, under the goal of energy saving and low carbon of nuclear power HVAC system, engineering designers should constantly optimize the design scheme in design procedure, plant Province based on the principles of energy saving, recovery and recycling, and find a balance between reliable technology and "green and low carbon", so as to provide reference and power for the sustainable development of nuclear power HVAC design and operation in China.

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