Analysis On Optimization Operation Of Cold End Of 600MW Wet Cooling Sub-critical Air Cooling Unit

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Abstract: Due to its remarkable water-saving characteristics, direct air cooling device has been widely used in carbon rich and water deficient areas in China. However, in the high temperature period in summer, the exhaust pressure of air cooling unit will rise greatly, the exhaust steam temperature will be high and the condensate temperature will be high. In this paper, Daihai Power Plant Phase I unit transformation as the research object, the cold end optimization of air cooling unit is analyzed, in order to improve the unit operation economy.

1. Introduction
In order to adapt to the new situation and improve the market competitiveness, we should actively create conditions and adopt advanced and mature technology to carry out technical transformation on backward equipment with poor economy and safety, strive to tap the internal potential, improve the reliability of units and reduce the operation cost, and further adapt to the requirements of deep peak load regulation of power grid, promote the improvement of technical equipment level of power plants and reduce the environmental impact Pollution. In order to improve the operation economy and provide reference for similar units, the wet cooling unit was changed into air cooling unit in Daihai Power Plant.

2. Definition of related concepts
The cold end system of steam turbine consists of low pressure final stage, condensing equipment and cooling equipment. Condensing equipment is an important part of optimizing the operation of steam turbine cold end system [¹]. Compared with other power plant energy-saving links, the cold end optimizes the energy-saving effect, with the highest energy-saving potential and more significant energy-saving effect. Generally speaking, cold end optimization can be divided into structural parameter optimization and operation parameter optimization. Optimization of operating parameters is to solve the problem of optimal cold end equipment under specific working conditions [²]. Combined to ensure maximum power generation and minimum unit carbon consumption as well as energy consumption of plant equipment. For a long time, the research on cold end optimization at home and abroad has been mainly focused on the equipment of traditional wet cooling unit (such as condenser) [¹].

The cold end system is an important part of the thermal cycle, and it is an important link to ensure that the steam that has completed the work of the steam turbine condenses continuously and participates in the new cycle [³]. In order to study the optimal operation mode of air-cooled condenser, it is necessary to study the optimal operation mode of air-cooled condenser, as well as the rapid development of various online monitoring and diagnosis systems. There is no big difference between Harmon indirect air cooling
unit and conventional unit, and the main research object is air cooling tower\[4\].

The back pressure of steam turbine is the centralized expression of the operation state of cold end system. It establishes a direct relationship between the change of cold end system state and the change of steam turbine power. Therefore, the quantitative calculation of the influence of exhaust pressure variation on unit economy has become an important part of cold end system characteristic model.

3. Direct air cooling system
The direct air cooling system uses external air to directly cool the exhaust of the steam turbine. The waste steam is discharged from the turbine's low-pressure cylinder and sent through a rough exhaust pipe to a heat-exchange tube on the air-cooling island. The axial fan sweeps the external cooling air through the beam of the heat pipe at a certain rate and exchanges heat with the steam in the pipe. The steam in the tube cools to condense and flows to the condensate collector.

The direct air cooling unit is susceptible to environmental flow field and temperature change, especially the high temperature and strong wind in summer. In fact, the air cooling unit also has the disadvantages of high back pressure, high carbon consumption and poor thermal economy. When the equipment is fully charged and the ambient temperature reaches 40°C, the backpressure of the equipment exceeds 30 kPa and the condensate water temperature is close to 70°C. The energy consumption rate of the air-cooled wind generator during the maximum load period in summer is between 1.0% and 1.5%. Reducing the backpressure of the unit is an effective method to improve the thermal economy of the unit. Therefore, increasing the cooling capacity of the cold end of the air cooling unit has become an effective method to ensure the safe operation of the direct air cooling unit in summer. In recent years, after the modification of the direct air cooling device system, the load capacity is improved and the effect of energy saving and consumption reduction is significant\[5\].

4. Optimization scheme
2 × 600MW Subcritical wet cooling coal-fired units were installed in Daihai phase I project, which were put into commercial operation in October 2005 and January 2006 respectively. The 1 × 10 unit of phase I was approved to increase to 630MW in March 2013, and the 2 × 600MW unit was approved to increase to 630MW in February 2015. The boiler, steam turbine and generator of phase I are designed and manufactured by Beijing Bawei Boiler Company, Shanghai steam turbine Company and Shanghai Steam Turbine Generator Company. The first stage unit of Inner Mongolia Daihai Power Generation Company has been running normally from commissioning to reconstruction. In response to the government’s policy of protecting Daihai Lake, it is decided to transform the first phase wet cooling unit into direct air cooling unit, so as to improve the flow efficiency of the unit, reduce the coal consumption of power supply and reduce the emission index. After modification, the unit has achieved the expected effect, and the unit 1 and unit 2 have passed the unit performance acceptance on August 24, 2019 and 5 respectively.

4.1 Water supply system
Two steam driven feed water pumps with 50% BMCR capacity and one electric starting standby feed water pump with 30% BMCR capacity are still used in the water supply system. The steam feed pump is arranged in the operation layer, which is different from that of the booster pump. The main renovation and accounting items of water supply system are as follows:

- One stage was added after No.1 high pressure heater, and external steam cooler was installed in No.3 high pressure heater. Under VVO condition, the feed water temperature increased from 280.4 °C to 284.8 °C.
- In order to improve the flue gas temperature at SCR inlet under low load, the boiler is equipped with graded economizer. The high-pressure water supply is changed to the inlet of primary classification economizer after the boiler.
- In order to avoid the steam temperature deviation caused by uneven heating on both sides of the boiler, the interface of the primary economizer at the side of the high-pressure feed water boiler is
changed from one side to two sides.

- After the steam turbine is changed from wet cooling to air cooling, the exhaust steam of feed pump turbine is directly discharged into the main engine exhaust device instead of the original one[6].

- Increase the utilization of waste heat of feed water flue gas. The design and layout of the system is provided by the flue gas waste heat manufacturer, and the interface is reserved in the design; the specific system is detailed in the boiler part.

- Calculation of feed pump turbine. The original feed water pump turbine is a wet cooling small turbine, and each unit is equipped with two 50% capacity feed pump turbines. The original design of feed pump turbine has low back pressure and long last stage blade. After the project is changed into an air-cooled unit, the exhaust steam of the small turbine is directly discharged into the large turbine, and the back pressure is correspondingly increased. The efficiency of the original small turbine will be greatly reduced when it operates at high back pressure. In addition, the small steam turbine has been operating for many years, and the efficiency has been reduced a lot, so the situation may be more serious. In addition, the last stage blade is longer, and the limit back pressure of the original small turbine is 28kpa, which can not fully adapt to the safe operation of higher back pressure condition after changing from wet cooling to air cooling. According to the calculation of small turbine manufacturers (Hangqi), they suggest that the flow path of the small turbine should be modified, and the blades more suitable for air cooling and high back pressure operation will significantly improve the economy. After negotiation with the power plant, the small steam turbine will not be replaced for the time being, but the operation of the small steam turbine needs to be closely monitored during the operation, and the back pressure operation shall be reduced if necessary[7].

- After calculation, the original feed water pump set can meet the operation needs after the transformation after the head of the front pump is restored to the original design head.

4.2 Drainage and exhaust system of high pressure heater

One external steam cooler of No.3 high pressure heater is added. Considering the safety factors, it is necessary to carry out partial transformation for No.1 and No.2 high pressure heaters. The steam pipe of No.1 high pressure heater is replaced, and the short cylinder body of No.2 high pressure heater is replaced. In consideration of the poor operation of No.3 high pressure heater before the transformation, there are problems such as large pipe plugging rate, big difference at the lower end, opening accident drainage all year round, and adding external steam cooler of No.3 high pressure heater, the No.3 high pressure heater is completely replaced. Except for the newly added external steam cooler of No.3 high pressure heater, the drain, drain and vent valves and pipes of No.1, No.2 and No.3 high-pressure heaters need to be replaced after accounting. Considering that the equipment has been running for many years, the set pressure of the safety valve should be returned to the factory for setting, and all the safety valves of the high-pressure heater should be replaced.

4.3 Closed circulating cooling water system

After the upgrading and transformation of large unit from wet cooling to air cooling, the circulating water system of large turbine and open circulating cooling water system of auxiliary machine are cancelled, and the cooling water system of auxiliary machine is changed to large closed water system, that is, all equipment cooling water in the plant is cooled by the evaporation cooling tower of hydraulic engineering, and the water quality is desalted water.

After the transformation, the water supply of the closed circulating cooling water system comes from the dry wet combined cooling tower outside the main power house. The cooling water is led out from the hydraulic cooling water supply pipe outside the main power house. After boosting by the auxiliary circulating water pump set at 0 m in the steam turbine room, it is sent to the heat exchange equipment. The cooling water return water is connected to the hydraulic cooling water return pipe outside the main power house and passes through the dry wet combined cooling tower. After cooling, it enters the cooling water supply system for recycling[8].
4.4 Vacuum system
The characteristics of air cooling unit, vacuum system volume is big wet unit, air leakage, and the original raw unit with small capacity, low pressure vacuum pump, cannot satisfy the demand of the air cooling unit vacuum system, therefore, each unit installed in the water ring vacuum pump group and two 100% capacity to meet the requirements of vacuum air cooling unit.

4.5 Cooling water system
The cooling water system of Daihai Power Plant adopts open cooling water system. The cooling water is sent to the condenser by circulating water pump for heat exchange. After being cooled by the cooling tower, the heated cooling water flows into the pool at the bottom of the cooling tower, and then is sent to the condenser by circulating water pump for circulation. Circulating cooling water is called circulating cooling water. The characteristic of the system is easy to cause scaling and corrosion.

5. Experimental study on performance of air cooled condenser

5.1 Purpose of the experiment
The purpose of the acceptance test of direct air-cooled condenser is divided into the following two types:
- When the ambient air temperature is 14 ℃, the air pressure is 873.3hpa, and the design wind speed is 4ms at 1m elevation of the top of steam distribution pipe, the exhaust steam volume of each steam turbine is 1186.061th, the exhaust enthalpy is 2450.9kj/kg, the exhaust steam volume of small steam turbine is 76.409th, and the exhaust enthalpy is 2538.6kj/kg. When the fan operates at 100% rated speed, the pressure at the outlet of exhaust device shall not exceed 9.5kpa.
- In summer, the ambient air temperature is 34 ℃, the air pressure is 878.0hpa, the design wind speed is 4m / s at 1m elevation of the top of steam distribution pipe, the exhaust capacity of each steam turbine is 1200.456h, the exhaust enthalpy is 2569kj / kg, the exhaust steam volume of small steam turbine is 109h, the exhaust enthalpy is 2710kj / kg, and the outlet pressure of exhaust steam is not more than 24kpa when the fan is running at 100% rated speed.
5.2 Test standards
- VGB's instruction on acceptance test and operation monitoring of air condenser in vacuum environment vgbr131me.
- American Society of mechanical engineers code for performance test of steam turbines (ANS1, ASME pto6.1).
- International Federation of water and steam properties: Industrial formula for thermodynamic properties of water and steam IAPWS-IF97.

5.3 Test process
- Before the test, the relevant test personnel of North China Electric Power Research Institute Co., Ltd. prepared the test program, which was approved by the power plant. During the test, the working condition was adjusted according to the test program and the system was isolated.
- The air cooling low temperature test of unit 1 in Daihai Power Plant was conducted at 23:00 on August 25, 2019. The unit load was 629mw, the frequency of air cooling fan frequency converter was 50 Hz, the wind speed was 0.58ms, the ambient temperature was 20.98 °C, the atmospheric pressure was 87.33kpa, and the pressure at the outlet of exhaust device was 13.41kpa.
- The air cooling high temperature test of unit 1 in Daihai Power Plant was conducted at 15:20-16:20 on August 18, 2019. The unit load was 628mw, the frequency of air cooling fan frequency converter was 50 Hz, the wind speed was 1.38ms, the ambient temperature was 26.93 °C, the atmospheric pressure was 86.71kpa, and the pressure at the outlet of exhaust device was 18.21kpa.

5.4 Test results
The relevant data are obtained through the test and the results are corrected. The comparison with the guaranteed value is as follows:

Table 1: comparison of experimental results and guaranteed values

| Serial number | Name                          | Unit | Guaranteed value | Experimental result |
|---------------|-------------------------------|------|------------------|---------------------|
| 1             | Steam turbine exhaust back pressure (low temperature) | kPa   | <9.5             | 9.27                |
| 2             | Steam turbine exhaust back pressure (high temperature) | kPa   | <24              | 23.32               |

6. Conclusion
Because the direct air cooling unit is easy to be affected by the environmental flow field and temperature changes, especially the high temperature and strong wind in summer. This paper optimizes the cold end working environment of the air cooling unit from the perspective of each system, improves the operation efficiency of the unit through the transformation, and ensures the safety and stability of the system operation. The comparison between the test results and the guaranteed value shows that the performance of the air-cooled condenser of No.1 steam turbine unit in Daihai Power Plant has met the requirements of the guaranteed value.

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