Analysis of Influence of Atmospheric Parameter Fluctuation on Condenser Pressure

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Abstract. The influence of atmospheric temperature, humidity and pressure fluctuation on the condenser pressure is analyzed by numerical simulation. The seasons are mainly divided according to the atmospheric humidity range, and the atmospheric data are classified according to the seasons, and the fluctuation range of atmospheric temperature, humidity and pressure in specific seasons is determined, and a simplified condenser pressure coupling calculation model is established. The hypothetical iterative procedure calculates the condenser pressure value within a certain seasonal range and a certain atmospheric parameter fluctuation range. The results show that the atmospheric temperature fluctuations have a great influence on the pressure of the condenser in the spring and autumn, atmospheric humidity and pressure fluctuations have a great influence on the condenser pressure in summer. The primary and secondary analyses were carried out on several parameters of the atmosphere. The influence of temperature on the pressure of the condenser was 93%, the weight of the humidity was 6.2%, and the weight of the pressure was 0.8%, which provided a basis for optimizing the operation mode of the cold end system.

1. Introduction
In thermal power and nuclear power generator sets, the cold end system is an important part of the thermal power unit, which has an important impact on the safe and economic operation of the unit [1-5], and the condenser is an important equipment for the cold end system, and its vacuum is directly related to the power generation efficiency of the thermal power plant. The pressure of the condenser is affected by the steam exhaust volume, atmospheric parameters, circulating water flow, condenser cleanliness, vacuum pump efficiency, cooling tower air volume, etc. Its solution is a complex calculation [6-9], at the same time, the atmospheric temperature and humidity conditions vary greatly in different seasons, the pump operation mode, fan operation mode, and cycle rate are also different. These factors are coupled to each other and affect the condenser pressure, thus affecting the economics of the unit [10-15]. This requires optimization of the algorithm in order to quantitatively analyze the influence of atmospheric parameters on the condenser pressure, in order to find the economic operation mode of the pump and the fan under certain atmospheric conditions in a certain season, and provide guidance for the economic operation of the unit.
2. Unit overview

2.1 Circulating water system
The circulating water system of the power plant unit adopts a secondary circulation expansion unit water supply system with mechanical ventilation cooling tower, one machine and two pumps. The pump operating conditions are: under pure coagulation conditions, one machine two pumps (high speed) are used in summer. The cooling rate is 60 times. The circulating water flow rate of each unit is about 7.61m$^3$/s. The flow rate of each pump is about 3.81m$^3$/s and the pump head is about 27.2m. In the spring and autumn, it is operated by one machine two (low speed). The cooling rate is 50.06 times, the cooling water flow rate of each unit is about 6.47m$^3$/s, the flow rate of each pump is 3.24m$^3$/s, the pump head is 24.8m, and one pump (high speed) is operated in winter, the cooling rate is 33.48 times. The circulating water flow rate of each unit is about 4.57m$^3$/s, the flow rate of each pump is 4.57m$^3$/s, and the head is 22.1m.

2.2 Atmospheric statistics
According to the meteorological statistics, the atmospheric parameters are statistically calculated according to the season, so that the fluctuation range of the calculation parameters can be narrowed, so that the influence of the fluctuation of the atmospheric parameters can be studied. The specific fluctuation range is shown in Table 1.

|            |            |            |            |
|------------|------------|------------|------------|
| Season     | (Spring and Autumn) | (Winter) | (Summer) |
|            | April to May, October to November | December, January to March | June to September |
| Temperature fluctuation range $/^{\circ}C$ | 10-25 | 1-15 | 21-31 |
| Air pressure fluctuation range $/Pa$ | 100.8-102.5 | 101.7-103 | 100.2-101.5 |
| Humidity fluctuation range $/%$ | 76-80 | 74-77 | 80-83 |

3. Condenser pressure calculation

3.1 Calculation condition
The atmospheric parameters were calculated by season. The effects of atmospheric temperature, atmospheric pressure and atmospheric humidity on the condenser pressure were calculated for each season. As shown in Table 2, a total of nine operating conditions were calculated. Taking winter as an example, working conditions 1-3 are respectively calculating the influence of fluctuations in atmospheric temperature, atmospheric pressure and atmospheric humidity on the condenser pressure in the range shown in Table 1. Working conditions 4-6 correspond to spring and autumn, working conditions 7-9 corresponds to summer.

| Calculation condition | atmospheric temperature $/{^{\circ}C}$ | atmospheric pressure $/Pa$ | atmospheric humidity $/%$ | Cooling water flow $/m^3.h^{-1}$ | Cooling ratio |
|----------------------|----------------------------------------|-----------------------------|---------------------------|---------------------------------|--------------|
| 1                    | 1-15                                   | 102.3                       | 75.5                      | 16452                           | 33.48        |
| 2                    | 8                                      | 101.5-103                   | 75.5                      | 16452                           | 33.48        |
| 3                    | 8                                      | 102.3                       | 74-77                     | 16452                           | 33.48        |
| 4                    | 10-25                                  | 101.6                       | 78                        | 23292                           | 50.06        |
| 5                    | 17.5                                   | 101-102.5                   | 78                        | 23292                           | 50.06        |
| 6                    | 17.5                                   | 101.6                       | 76-80                     | 23292                           | 50.06        |
| 7                    | 21-31                                  | 100.8                       | 81.5                      | 27396                           | 60           |
3.2 Power tower calculation
The known data are atmospheric pressure $P_a$, inlet air dry temperature $t_a$, and inlet air wet bulb temperature $t_m$, circulating water quantity $Q$, turbine exhaust volume $D_a$, condenser parameters, and power tower parameters. The amount to be determined is the gas air volume $G$, export water temperature of the power tower $t_{w2}$, the condenser temperature $t_c$, and the number of cooling tasks $N_c$.

The cooling tower capacity $N_c$ is calculated as follows:

$$N_c = a \cdot \text{lambda}^b$$  \hspace{1cm} (1)

In the middle: $\text{lambda}$ — Gas to water ratio, calculated according to the following formula.

$$\text{lambda} = \frac{r_{\text{hom}} \cdot G}{A_f \cdot q}$$  \hspace{1cm} (2)

In the middle: $r_{\text{hom}}$ — Air density, kg·m$^{-3}$; $G$ — Tower air volume, m$^3$·s$^{-1}$; $A_f$ — Mechanical tower ventilation cross section, m$^2$; $q$ — Water density, kg·m$^{-2}$·s$^{-1}$.

The number of cooling tower tasks $N_c$ is calculated as follows:

$$N_c = \frac{C_w \cdot \Delta t}{6} \left( \frac{1}{i_2 - i_1} + \frac{4}{i_m - i_m} + \frac{1}{i_1 - i_2} \right)$$  \hspace{1cm} (3)

In the middle: $C_w$ — Circulating water specific heat capacity, kJ·kg$^{-1}$·°C$^{-1}$; $\Delta t$ — Circulating water temperature difference, °C; $i_1$, $i_2$ — Enthalpy of saturated gas and corresponding gas of the outlet water temperature, kJ·kg$^{-1}$; $i_m$, $i_m$ — Enthalpy of saturated gas and corresponding gas of the average inlet and outlet water temperature, kJ·kg$^{-1}$.

Assume that the initial flow rate of the power tower fan $G$ is 500 m$^3$·s$^{-1}$, and the air density can be obtained by entering the air dry and wet bulb temperature of the tower. Through the calculation of the resistance and the correlation curve, the wind turbine resistance $H_c$ and the total pressure of the fan $H_a$ can be obtained. Along with the air volume increases, the total pressure of the fan decreases, and the fan resistance rises, therefore there is a certain air volume $G_0$, so that $H_c$ is equal to $H_a$, and the air volume is the required air volume.

Further, the cooling capacity $N_c$ of the cooling tower and the number of cooling tasks $N_t$ can be obtained by the formulas (1) and (3), assuming that the water temperature of the tower is $t_{w1}$, and there is also a tower water temperature $t_{w2}$, so that $N_c$ is equal to $N_t$, and the outlet temperature $t_{w2}$ is under the condition of the inlet water temperature $t_{w1}$.

3.3 Condenser calculation
Assuming that the steam exhaust steam temperature is $t_{s1}$, the temperature difference $dt$ of the inlet and outlet water can be calculated. It is considered that the temperature difference between the inlet and outlet of the circulating water is equal to the temperature difference between the inlet and outlet of the cooling tower. There is a certain water temperature hypothesis value $t_{w1}$, so that the temperature difference between the inlet and outlet towers is equal to $dt$, $t_{w1}$ is the inlet water temperature, then the turbine exhaust steam temperature $t_s$ can be obtained, and there is a certain assumed value $t_{s1}$, so that $t_s$ is equal to $t_{s1}$, this temperature $t_{s1}$ is the condenser temperature, and its corresponding saturated vapor pressure $P_a$ is the condenser pressure.
4. Analysis and conclusion

4.1 Influence of atmospheric temperature on condenser pressure

As shown in Figure 1, in winter (December, January to March), the relative humidity of the atmosphere increases from 1 °C to 15 °C (the relative humidity and pressure of the atmosphere are unchanged), and the condenser pressure is increased from 6.0 kPa to 8.2 kPa, increased by 2.2 kPa; spring and autumn (April to May, October to November), atmospheric temperature increases from 10 °C to 25 °C (atmospheric relative humidity and pressure unchanged), condenser pressure by 6.08kPa increased to 8.8kPa, increased by 2.72kPa; in summer (June to September), atmospheric relative humidity increases from 21 °C to 31 °C (atmospheric relative humidity and pressure unchanged), condenser pressure from 6.85 The kPa increases to 9.4 kPa, which is increased by 2.55 kPa.

The air temperature fluctuation affects the temperature of the inlet and outlet water, which in turn affects the condenser pressure. The calculation results show that the condenser pressure increases with the inlet air temperature rises. This is because the average temperature difference between the air and the cooling water in the cooling tower decreased as the temperature of the inlet air rises, resulting in an increase in the temperature of the inlet and outlet water and an increase in the condenser pressure. At the same time, it can be seen from the graph that the condenser pressure with the variation of the atmospheric temperature (curve slope) is the largest in summer, followed by spring and autumn, and the smallest in winter. From the perspective of fluctuation range, the fluctuation of condenser pressure caused by atmospheric temperature in spring and autumn is greater than that in summer. Therefore, it is necessary to focus on the influence of temperature difference between day and night in spring and autumn on condenser pressure.
4.2 Influence of atmospheric humidity on condenser pressure

As shown in Figure 2, in winter (December, January to March), the atmospheric relative humidity increases from 74% to 77% (the atmospheric dry bulb temperature and pressure did not change), and the condenser pressure increases from 6.976 kPa to 7.014 kPa, increased by 0.038 kPa; in spring and autumn (April to May, October to November), atmospheric relative humidity increases from 76% to 80% (atmospheric dry bulb temperature and pressure unchanged), condenser pressure increases from 7.195 kPa to 7.277 kPa, increased by 0.082 kPa; in summer (June to September), the atmospheric relative humidity increases from 80% to 83% (the atmospheric dry bulb temperature and pressure are unchanged), condenser pressure increases from 7.918 kPa to 8.03 kPa, an increase of 0.112 kPa.

Atmospheric humidity affects the temperature of the inlet and outlet water by affecting the density and enthalpy of the incoming tower air, resulting in changes in condenser temperature and pressure. The calculation shows that the condenser pressure increases with the increase of atmospheric humidity. This is because the air enthalpy difference of import and export air decreased as humidity increases, the tower cooling task increases, results in the tower water temperature and condenser pressure rising. From the curve, the influence of atmospheric humidity on the condenser (curvature slope) sorted from big to small is: summer, spring and autumn, winter. From the perspective of fluctuation range, the condenser pressure fluctuation caused by atmospheric humidity in summer is higher than that in spring and autumn, the fluctuation range in winter is smaller. Therefore, it is necessary to focus on the atmospheric humidity fluctuation in summer.

4.3 Influence of atmospheric pressure on condenser pressure

It can be seen from Figure 3 that in winter (December, January to March), the atmospheric pressure increases from 101.5 kPa to 103 kPa (the atmospheric dry bulb temperature and humidity do not
change), and the condenser pressure increases from 6.989 kPa to 7.001 kPa, increased by 0.012 kPa; in spring and autumn (April to May, October to November), the atmospheric pressure increases from 101 kPa to 102.5 kPa (the atmospheric dry bulb temperature and humidity are unchanged), the condenser pressure increases from 7.23 kPa to 7.245 kPa, increased by 0.015 kPa; in summer (June to September), the atmospheric pressure increases from 100 kPa to 101.5 kPa (the atmospheric dry bulb temperature and humidity are constant), and the condenser pressure increases from 7.964 kPa to 7.780 kPa, an increase of 0.016 kPa.

Atmospheric pressure fluctuations affect the air density, which affects the gas-water ratio of the cooling tower, and then affects the cooling task of the cooling tower, resulting in fluctuations in the temperature of the inlet and outlet towers, finally the condenser pressure changes. The calculation results show that the condenser pressure increases with the increase of atmospheric pressure. This is because as the atmospheric pressure increases, the difference between the outlet air of the cooling tower and the inlet air decreases, resulting in an increase in the cooling task and the condenser pressure. It can be obtained from the curve that the fluctuation range of the condenser pressure with atmospheric pressure (the slope of the curve) from high to low is: summer, spring and autumn, winter. From the perspective of fluctuation range, the condenser pressure fluctuation caused by atmospheric pressure in summer is higher than that in spring and autumn, and the fluctuation range in winter is smallest. Therefore, it is necessary to focus on the atmospheric pressure fluctuation in summer.

5. Conclusion
1) Through the above analysis, within the calculation range, the atmospheric temperature fluctuation has the greatest influence on the condenser pressure, accounting for 93% of the total atmospheric impact, atmospheric humidity accounting for 6.2%, and atmospheric pressure accounting for only 0.8%. From a seasonal perspective, the order of influence of atmospheric parameter changes on the
condenser pressure is ranked from high to low: summer, spring and autumn, winter, from the perspective of fluctuations, atmospheric humidity and pressure have the greatest influence on condenser pressure in summer, and atmospheric temperature has the greatest influence on condenser pressure in spring and autumn.

2) In the optimization of cold-end system, it is necessary to closely combine the fluctuation characteristics of atmospheric temperature and humidity, such as temperature difference between day and night, temperature and humidity during rainfall. In summer, we should focus on the impact of precipitation on temperature and humidity, and we should focus on the influence of temperature difference between day and night in other seasons.

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