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Study on thermodynamic system characteristics of thermoelectric units under variable operating conditions

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Abstract. The variable working condition of thermal system refers to that the working condition in the system changes, deviates from the design working condition or deviates from a certain reference working condition. There are various reasons for the change of thermal system's off design condition, including the change of unit heat load, the change of thermal system and equipment, and the change of steam parameters and reheat parameters. The purpose of variable condition calculation of thermodynamic system is to determine the steam parameters of each extraction port and exhaust end of the turbine and the corresponding parameters of the regenerative system. Its essence is to determine the new expansion process line and system parameters of the turbine. This is the basis for the safety and reliability analysis of the system under off design conditions and the calculation and analysis of economic indicators. Through the research on the electrothermal coupling characteristics of thermoelectric units under variable operating conditions, it can provide data support for the power grid dispatching department to master the electrical output characteristics of thermoelectric units in heating seasons.

key word: Thermoelectric unit; Off design condition calculation; thermodynamic system.

1. Introduction

The variable working condition of thermal system refers to that the working condition in the system changes, deviates from the design working condition or deviates from a certain reference working condition[1]. There are various reasons for the change of thermal system's off design condition, including the change of unit heat load, the change of thermal system and equipment, and the change of steam parameters and reheat parameters.
The purpose of variable condition calculation of thermodynamic system is to determine the steam parameters of each extraction port and exhaust end of the turbine and the corresponding parameters of the regenerative system[2]. Its essence is to determine the new expansion process line and system parameters of the turbine. This is the basis for the safety and reliability analysis of the system under off design conditions and the calculation and analysis of economic indicators.
Affected by the information segmentation between power grid and heat supply network, the traditional electric heat dispatching is to conduct real-time balancing in their respective regions[3]. At present, it is more and more difficult to balance power supply and demand, so it is necessary to carry out research and application promotion of electric heating coordination optimization technology from the perspective of energy supply system[4].

2. Study on off design calculation of thermodynamic system

2.1 Basic Steps of Off design Calculation

(1) Original calculation. According to the data obtained, the original working condition (i.e. the selected benchmark working condition) shall be calculated in detail and correctly by different methods (heat balance method, cycle function method or other methods), with the main purpose of obtaining detailed data required for subsequent calculation. These data mainly include steam extraction volume at all levels, flow rate at all levels, and main thermal economic indicators.
(2) Preliminary calculation. The variable (generally the flow of live steam) specified in the off design condition is directly substituted into the thermal system, while all other parameters are reserved as the values under the original working condition for the principled thermal system calculation of the whole plant. The primary function of the preliminary calculation is to provide calculation conditions and basis for the subsequent iterative calculation.
(3) Iterative calculation. Each iteration calculation repeats a process: all steam and water parameters of the new round and the flow rate of each stage of the turbine are

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obtained through iteration from all steam and water parameters obtained from the previous calculation and the flow rate of each stage of the turbine.
Each iteration calculation will be carried out in two steps. The first step is preliminary calculation. The steam parameters (mainly extraction pressure and specific enthalpy) shall be corrected before this calculation by using the conclusions from the last calculation (the first iteration is the result of preliminary calculation). The specific correction method is shown below. The second step is basic calculation. Make use of the conclusions obtained from the preliminary calculation to carry out the calculation of the plant's principled thermodynamic system to prepare for the next iteration.
(4) End of iteration. If the calculation is carried out according to the above three steps, the results obtained will continue to approach the real situation, but an end condition needs to be given to complete the calculation[5]. Theoretically, the end condition of iteration calculation is that the steam parameters and flow rate obtained from the previous and subsequent two iterations are equal. However, considering the practicability of engineering problems, a minimum error is given in this project. When the calculation results of two iterations are less than the specified minimum error, it is considered that the calculation results meet the requirements and the iteration is completed.

2.2 Theoretical Basis of Off design Condition Calculation

(1) Determination of extraction pressure change

Flügel formula is the relationship between the turbine flow and the parameters before and after the stage. The expression is:

$$\frac{D_1}{D_{10}} = \frac{\sqrt{p_1^2 - p_2^2}}{\sqrt{p_{10}^2 - p_{20}^2}} \frac{\sqrt{T_{10}}}{\sqrt{T_1}} \tag{1}$$

In the formula:
D10, D1 -- stage flow before and after working condition change, t/h;
T10, T1 -- temperature before and after working condition change, ℃;
P10, p1 -- pre stage pressure before and after working condition change, MPa;
P20, p2 -- pressure after stage before and after working condition change, MPa
The formula is derived under the condition that the steam flow and flow area of the flow passage part of the steam turbine remain unchanged. For condensing units, it is considered that the regenerative steam extraction volume is approximately proportional to the heating steam flow, so Freugel formula can also be used. For heat supply extraction steam turbine, Freugel formula can also be used in sections to complete the calculation of the unit thermal system under variable conditions.
In case of variable working conditions, the influence of temperature correction term can be basically ignored. In general, p2/p1 between two steam extraction ports is very small, so equation (1) can be simplified as follows:

$$\frac{D_1}{D_{10}} = \frac{p_1}{p_{10}} \tag{2}$$

Through the calculation of the off design condition of the 135MW unit of Harbin Turbine Group Co., Ltd. and the 330MW unit of Dongfang Turbine Group Co., Ltd., and the comparison of the off design condition parameters in the thermal characteristics book, it is found that the accuracy requirements can be met by using Formula (2) to correct the extraction pressure.

(2) Determination of relative internal efficiency of steam turbine
In the approximate calculation of the variable working conditions of the steam turbine, the efficiency of the governing stage and the last stage varies greatly, while the internal efficiency of other pressure stage groups basically remains unchanged when the working conditions change, and the steam state line shows a process line of parallel movement. In the calculation of specific units, the internal efficiency of each unit can be verified through the thermal characteristics book, which can well prove the above theory.
The internal efficiency of the regulating stage can be calculated according to the flow efficiency curve of the manufacturer. In the absence of the manufacturer's curve, the internal efficiency curve of the regulating stage can be fitted according to the thermal test results.
The last stage efficiency curve can also be checked according to the characteristics of the manufacturer's variable working conditions[6]. For the final stage, the main loss is wet steam loss. The internal efficiency of the final stage can also be calculated from the change of wet steam loss. It is generally believed that the unit efficiency will decrease by 1% when the average steam humidity of the final stage group increases by 1%.
The detailed calculation of steam turbine condenser under off design conditions is very complicated, and the calculation formula using the simplified algorithm is as follows:

$$t_k = t_{w1} + \frac{D_k q_k}{C_W G_W [1 - \exp(-k_0 (-\frac{G_w}{G_{w0}})^{0.5} \frac{F_k}{C_w G_w}]} \tag{3}$$

In the formula:
Dk -- cooling water entering condenser, t/h;
Qk -- Condensation heat release of 1kg exhaust steam in condenser, t/h;
CW -- Specific heat of cooling water, J/(kg. C);
M -- cooling ratio
When the cooling water operates normally, the air partial pressure is very small and can be ignored. The calculated saturated water pressure corresponding to the saturated water temperature is the condenser pressure under variable working conditions.
For the calculation in this paper, since the influence of the condenser mainly lies in the final stage exhaust pressure, it has little influence on the overall off design condition calculation. At the same time, the condenser pressure is selected as the rated pressure of the condenser according to the thermal characteristics book under off design condition.

(3) Determination of Extraction Point Parameters and Hydrograph

In the calculation of the off design condition of the thermal system, the steam parameters at each extraction point are determined first and the process line of the operation condition change is drawn on the enthalpy entropy diagram of the water steam. The extraction pressure of each stage and the new exhaust pressure under the new working condition are determined by Freugel formula. Then determine the internal efficiency of each unit according to the determination method of internal efficiency of each unit.

The extraction enthalpy and exhaust enthalpy of each group can be further obtained by the obtained pressure of each extraction point and the efficiency value in each group. According to the definition of relative internal efficiency of steam turbine, the internal efficiency calculation formula of any stage group r is:

$$\eta_{oi(r)} = \frac{h_{i(r)} - h_{2(r)}}{H_{a(r)}} \quad (4)$$

From this, the formula of extraction enthalpy at all levels can be obtained as follows:

$$h_{2(r)} = h_{1(r)} - H_{a(r)}\eta_{oi(r)} \quad (5)$$

In the formula:

$h_{1(r)}$, $h_{2(r)}$ -- enthalpy value of steam at the inlet and outlet of stage r, kJ/kg;

$H_{a(r)}$ —— isentropic expansion enthalpy drop of steam in steam turbine of stage r group, kJ/kg;

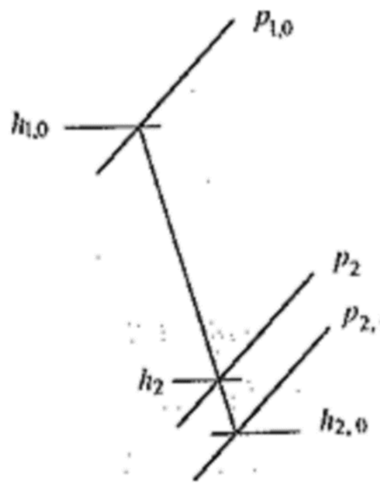

Figure 1 etermination of Specific Enthalpy at Inlet and Outlet of Unit

The peak shaving capacity of thermal power units is the highest and lowest electrical load that the unit can reach under a certain external steam extraction capacity. The limiting conditions for different types of thermal power units to carry the highest and lowest electrical loads are also different.

(4) Determination of water enthalpy at heater outlet

To determine the outlet water enthalpy of the heater, the variable working conditions of the heater shall be considered to determine the corresponding end difference and heat transfer coefficient. Considering the small change of end difference and the requirement of calculation speed, this paper does not consider the variable working condition of the heater when determining the steam and water parameters at each point of the thermal system. The upper and lower end difference of the heater is obtained from the thermal characteristics book and considered to be unchanged. According to the definition of heater end difference and the known outlet pressure of feed water pump and condensate pump, the outlet water temperature, outlet water enthalpy and outlet drain water temperature and enthalpy of heaters at all levels can be determined.

(5) Analysis of auxiliary steam and water components

Various auxiliary steam and water components in the thermal system mainly include the utilization of shaft seal steam leakage, steam used by steam extractors, valve stem steam leakage and blowdown expansion steam, etc. They should be correctly treated in the calculation of variable working conditions to ensure the reliability of the calculation. According to the theory in reference [2], the steam leakage parameters of the unit change with the change of the source parameters, and the steam leakage flow changes proportionally with the change of the live steam flow

3. Conclusion

In the analysis of Harbin Turbine 135MW unit, the heat supply and steam extraction together with the subsequent flow passage are treated as the fourth stage flow passage. It can be seen that when the extraction pressure rises, the internal efficiency of the unit decreases under the same flow rate; On the contrary, the efficiency in the unit increases.

There are few known data under heating and steam extraction conditions, but it can still be seen that under the same steam extraction pressure conditions, the internal efficiency of the fourth stage is approximately linear with the flow rate of the fourth stage. Therefore, the piecewise linear interpolation method is also used to solve the fourth stage internal efficiency under variable conditions.

The final stage wet steam loss is the main reason for the change of the final stage efficiency under off design conditions. Generally speaking, the unit efficiency will decrease by 1% when the average steam humidity increases by 1%. Because the change of the last stage steam humidity is caused by the change of the last stage flow rate in the variable working conditions, the relationship curve between the last stage flow rate and the internal efficiency is needed to find its corresponding relationship.

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electric heating coordination optimization under guaranteed supply demand.

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