Sensitivity Analysis of Steam Turbine Unit Real-time Data Based on Energy Consumption Characteristics

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ABSTRACT

Taking N630-24.2/566/566 turbine unit of Shanghai Turbine Plant as the research object, the sensitivity analysis of real-time data of turbine unit under sliding pressure conditions of THA, 75%THA, 50%THA, 40%THA and 30%THA was carried out by using the calculation method of constant The sensitive factors of each parameter to energy consumption under different working conditions are calculated by Delphi The results show that the thermal economy of the unit can be effectively improved by ranking the energy consumption sensitivity of the The results show that the thermal economy of the unit can be effectively improved by ranking the energy consumption sensitivity of the measuring point parameters according to the size of the sensitive factors, focusing on the parameters of the measuring point with strong energy The results show that the thermal economy of the unit can be effectively improved by ranking the energy consumption sensitivity of the measuring point parameters according to the size of the sensitive factors, focusing on the parameters of the measuring point with strong energy consumption sensitivity and making corresponding adjustments in time.

Keywords: Steam turbine; Sensitivity analysis; Turbine variable operating condition; Sensitive factor

1. INTRODUCTION

At present, power generation is still the main force of power generation in our country, and as an important part of thermal power unit, the large amount of real-time data generated by the steam turbine is very important for the thermal economy of the unit. In the actual operation of the unit, due to the aging tendency of the equipment over time and the possible failure of the measuring instrument, the real-time data of the online monitoring system is distorted, thus affecting the thermal economy of the unit [1-2]. The large amount of data produced in the running process of steam turbine unit has different influence on energy consumption, so we should pay more attention to the parameters which have great influence on energy consumption, so as to achieve the purpose of energy saving and consumption reduction. It is of great significance to realize the weight ranking of the influence of real time data on energy consumption of steam turbine units.

China aims to achieve carbon peak before 2030 and carbon neutrality before 2060, so it is very important to improve the thermal economy of thermal power units. Therefore, it is urgent to carry out thermal economy analysis and operation optimization of thermal power units. Xue Yuncan et al. adopted partial differential method and equivalent enthalpy drop method to maintain the same back pressure and quantitatively calculate the influence of main steam parameters on coal consumption rate, and analyzed and compared them to guide the operation of the unit [3]. Bai Jingru et al. analyzed the magnitude and distribution of the influence of the end difference of the heater on energy consumption by using equivalent enthalpy drop method for a 1000MW ultra-supercritical secondary reheating unit, providing a reference for improving the thermal economy of the same type of unit [4]. Yang Yu et al. made a theoretical analysis on the influence of small deviations of key parameters in the basic definition formula of heat consumption of steam turbine, and obtained a method for evaluating the sensitivity of the efficiency of high pressure cylinder, medium pressure cylinder and low pressure cylinder of steam turbine to heat consumption rate [5]. Yang Zhiping et al. analyzed the sensitivity of steam turbine exhaust pressure to steam turbine heat consumption, coal consumption for power generation and coal consumption for power supply under different working conditions, which has a guiding effect on the economic operation of steam turbine [6]. Yan Shunlin et al. established a turbine operating condition model with variable initial parameters and combined with the basic equation of economic analysis of the thermodynamic system, analyzed the energy consumption sensitivity of the main steam pressure, main steam temperature and reheated steam temperature under different operating conditions [7]. Wang Bo et al. adopted the calculation method of constant power variation condition

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to analyze the sensitivity of turbine flow efficiency and obtained the influence rule of the variation of each cylinder flow efficiency on the heat consumption rate of turbine unit [8].

This paper establishes a theoretical analysis model of the whole system with constant power and variable operating conditions through Delphi software programming, and calculates the sensitivity factors of each measurement point for the internal operating state parameters inherent in the boundary conditions and equipment structure, i.e., the real-time data of all possible distortion measurement points that affect energy consumption, makes the sensitivity curves of the measurement points with strong sensitivity to energy consumption, analyzes the degree of influence of each parameter on energy consumption and gives the The corresponding optimization measures are given.

2. REAL-TIME DATA SENSITIVITY ANALYSIS MODEL FOR EACH MEASUREMENT POINTS OF TURBINE UNIT

2.1 Energy Consumption Sensitivity Analysis Process

Taking the 630MW supercritical intermediate reheat condensing turbine unit as the research object, the sensitivity analysis model of THA condition is established by the heat balance diagram given by the manufacturer, and the 75% THA, 50% THA, 40% THA and 30% THA sliding pressure condition analysis models are established respectively according to the given typical sliding pressure operating condition inlet pressure curve.

In this paper, the energy consumption sensitivity analysis is based on the internal operating state parameters inherent to the boundary conditions and the equipment structure. The sensitivity of each measurement point parameter to energy consumption can be calculated based on the fact that the deviation of a parameter due to inaccurate measurement of the instrument is a subjective change and does not lead to changes in other parameters. The sensitivity analysis of the energy consumption of the turbine unit is carried out by keeping the output power of each working condition constant through the established analysis model and changing the values of the measured parameters under different working conditions, and the analysis process is shown in Figure 1.

2.2 Definition of Energy-Sensitive Factors

The supply coal consumption rate is the most basic energy consumption characteristic of thermal power units and is usually expressed by b_{sn}

$$b_{sn} = \frac{123}{\eta_b \eta_i \eta_m \eta_g \eta_p (1 - \sum \xi_i)} \tag{1}$$

Where: b_{sn} is the supply coal consumption rate, $g/(kW \bullet h)$; η_b is the boiler efficiency; η_i is the cycle thermal efficiency; η_m is the mechanical efficiency; η_g is the generator efficiency; η_p is the piping efficiency; $\sum \xi_i$ is the thermal efficiency of each auxiliary machine.

As can be seen from equation (1), the coal consumption rate of power supply is related to many factors and involves a large number of measurement parameters. When the measurement parameters change, the coal consumption rate of power supply is bound to change accordingly, and the measurement points are changed from $x_1, \cdots, x_i, \cdots, x_n$ to $x_1', \cdots, x_i', \cdots, x_n'$ and the variables are $\Delta x_1, \cdots, \Delta x_i, \cdots, \Delta x_n$, and the coal consumption rate of power supply is changed from b_{sn} to b_{sn}' and the variables are Δb_{sn} . The Taylor expansion of the multivariate function is expressed as

$$\Delta b_{sn} \approx \frac{\partial b_{sn}}{\partial x_1} \Delta x_1 + \cdots + \frac{\partial b_{sn}}{\partial x_i} \Delta x_i + \cdots + \frac{\partial b_{sn}}{\partial x_n} \Delta x_n \tag{2}$$

The deviation of a parameter at a measurement point due to inaccurate measurement of the measuring instrument is a subjective change, not an objective change, and does not lead to corresponding changes in other parameters. For a change in a measurement point parameter x_i Δx_i resulting in a change in the coal consumption rate of the supply b_{sn} Δb_{sn} , it can be expressed as

$$\Delta b_{sn,xi} = \frac{\partial b_{sn}}{\partial x_i}\Delta x_i \tag{3}$$

b_{sn} The change in the supply coal consumption ratecaused by the change in the measurement point parameter x_i is called the sensitivity of the measurement point parameter x_i to the supply coal consumption rate . b_{sn} [9]The energy consumption sensitivity factor S_i is defined as the ratio of the rate of change of the coal consumption rate b_{sn} to the rate of change of a measurement point parameter x_i . It can be expressed as:

$$S_i = \frac{\Delta b_{sn,xi}/b_{sn}}{\Delta x_i/x_i} = \frac{\left(\frac{\partial b_{sn}}{\partial x_i}\Big/\Delta x_i\right)\Big/b_{sn,xi}}{\Delta x_i/x_i} = \frac{\partial b_{sn}}{\partial x_i}\bullet\frac{x_i}{b_{sn}} \tag{4}$$

The energy consumption sensitivity factor is not fixed, but changes with different operating modes, environment, load and equipment characteristics. When the energy consumption sensitivity factor is greater than 0, it indicates that the change of measurement point parameters and coal consumption are positively correlated; when the energy consumption sensitivity factor is less than 0, it indicates that the change of measurement point parameters and coal consumption are negatively correlated. The analysis of the energy consumption sensitivity factor is mainly in three aspects: 1. the influence on coal consumption when the value of a measurement point parameter fluctuates in a certain range under different working conditions; 2. the change of energy consumption sensitivity factor caused by the change of measurement point parameter at the same working condition; 3. the change of energy consumption sensitivity factor corresponding to the change of load at different working conditions. The energy consumption sensitivity factor of each measurement point parameter is calculated by Delphi software programming.

3. SENSITIVITY ANALYSIS OF 630MW SUPERCRITICAL TURBINE UNIT REAL-TIME DATA ENERGY CONSUMPTION

3.1 Design Parameters of 630MW Supercritical Turbine Unit

The above steam N630-24.2/566/566 turbine unit is the object of study. The turbine adopts a three-stage high-pressure heater, a one-stage deaerator and a four-stage low-pressure heater to form an eight-stage heat return system, with the hydrophobic flow of the high-pressure heater to the deaerator and the hydrophobic flow of the low-pressure heater to the condenser. In THA operating conditions feed pump efficiency is 81%, feed pump turbine efficiency is 83%, its generator efficiency is 98.9%, the back pressure is 5.88kPa. # 1, # 2, # 3 high-pressure heater pumping pipe pressure loss is 3%, reheat system pressure loss is 10%, the rest of each heater pumping pipe pressure loss is 5%. The heater end difference is shown in Table 1, and the design parameters of the measurement points under THA conditions are shown in Table 2.

Table 1. Heater end difference of 630MW unit rated working condition

	1# Geauga	2# Geauga	3# Geauga	5# Low Plus	6# Low Plus	7# Low Plus	8# Low Plus
Upper end difference/°C	-1.7	0	0	2.8	2.8	2.8	2.8
Lower end difference/°C	5.6	5.6	5.6	5.6	5.6	5.6	5.6

Table 2. Design parameters of measurement points under THA conditions of 630MW unit

Name	Design value	Name	Design
Unit power/MW	630	Eight pumping pressure/MPa	0.021
Main steam pressure/MPa	24.2	Eight pumping temperature/℃	61.5
Main steam temperature/℃	566	#1 Heater outlet water temperature/℃	277.4
One pumping pressure/MPa	6.204	#2 Heater outlet water temperature/℃	251.2
One pumping temperature/℃	356.2	#3 Heater outlet water temperature/℃	206.3
Secondary pumping pressure/MPa	4.181	Deaerator outlet water temperature/℃	174.9
Second extraction temperature/℃	307.3	Feed pump outlet water temperature/℃	180.5
Reheat pressure/MPa	3.763	#5 Heater outlet water temperature/℃	138.7
Reheat temperature/℃	566	#6 Heater outlet water temperature/℃	106.4
Triple pumping pressure/MPa	1.826	#7 Heater outlet water temperature/℃	74.29
Triple pumping temperature/℃	453	#8 Heater outlet water temperature/℃	57.6
Four pumping pressure/MPa	0.937	Condensate temperature/℃	35.87
Four pumping temperature/℃	357	#1 Heater hydrophobic temperature/℃	256.7
Five pumping pressure/MPa	0.397	#2 Heater hydrophobic temperature/℃	211.9
Five pumping temperature/℃	252	#3 Heater hydrophobic temperature/℃	186
Six pumping pressure/MPa	0.147	#5 Heater hydrophobic temperature/℃	111.9
Six pumping temperature/℃	147.1	#6 Heater hydrophobic temperature/℃	79.84
Seven pumping pressure/MPa	0.044	#7 Heater hydrophobic temperature/℃	63.16
Seven pumping temperature / ℃	78.3	#8 Heater hydrophobic temperature/℃	42.23

3.2 Sensitivity Calculation and Analysis of Real-time Data Energy Consumption of Turbine Units

According to the establishment of different working condition models of turbine units, the sensitivity factors of each measurement point parameter under THA, 75% THA, 50% THA, 40% THA and 30% THA sliding pressure working conditions are calculated, and the magnitude of the sensitivity factor is the deviation degree of the measurement point parameter on energy consumption. In order to better reflect the influence degree of the measurement point parameter on energy consumption, the energy consumption sensitivity factor is processed by taking the absolute value. In order to better reflect the degree of influence of the measured parameters on energy consumption, the energy consumption sensitivity factors are treated as absolute values. And make the sensitivity factor curve of the measurement point parameters with greater influence on coal consumption as shown in Figure 2.

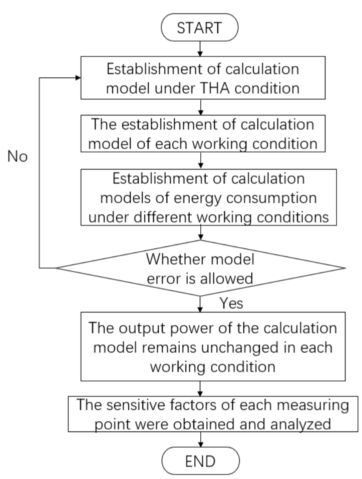

Figure 1. Analysis flow chart

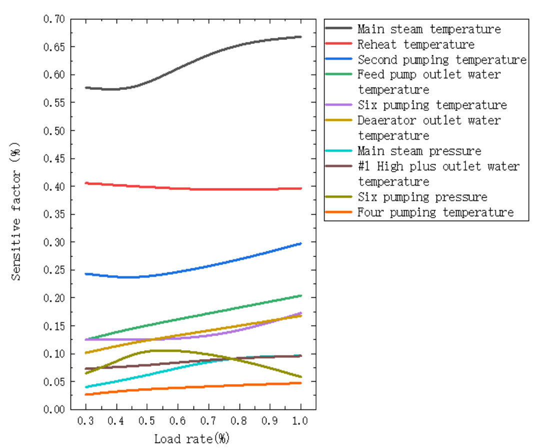

Figure 2. Sensitivity factor curve

Table 3. Ranking of energy consumption sensitivity weights for each working condition

	THA	75% THA	50% THA	40% THA	30% THA
1	Main steam temperature	Main steam temperature	Main steam temperature	Main steam temperature	Main steam temperature
2	Reheat temperature	Reheat temperature	Reheat temperature	Reheat temperature	Reheat temperature
3	Second pumping temperature	Second pumping temperature	Second pumping temperature	Second pumping temperature	Second pumping temperature
4	Feed pump outlet water temperature	Feed pump outlet temperature	Feed pump outlet temperature	Feed pump outlet temperature	Six pumping temperature
5	Six pumping temperature	Deaerator outlet temperature	Six pumping temperature	Six pumping temperature	Feed pump outlet temperature
6	Deaerator outlet water temperature	Six pumping temperature	Deaerator outlet temperature	Deaerator outlet temperature	Deaerator outlet temperature
7	#1 High plus outlet water temperature	Six pumping pressure	Six pumping pressure	Six pumping pressure	#1 High plus outlet water temperature
8	Main steam pressure	Main steam pressure	#1 High plus outlet water temperature	#1 High plus outlet water temperature	Six pumping pressure
9	Six pumping pressure	#1 High plus outlet water temperature	Main steam pressure	Main steam pressure	Main steam pressure
10	Four pumping temperature	Four pumping temperature	Four pumping temperature	Four pumping temperature	Four pumping temperature
11	Second pumping pressure	Second pumping pressure	Eight pumping pressure	Eight pumping pressure	Eight pumping pressure
12	Eight pumping pressure	Eight pumping pressure	Second pumping pressure	Second pumping pressure	#2 High plus outlet water temperature
13	One pumping temperature	One pumping temperature	One pumping temperature	#5 Low plus outlet water temperature	#5 Low plus outlet water temperature
14	#2 High plus outlet water temperature	#2 High plus outlet water temperature	#5 Low plus outlet water temperature	#2 High plus outlet water temperature	#3 High plus outlet water temperature
15	#5 Low plus outlet water temperature	#5 Low plus outlet water temperature	#2 High plus outlet water temperature	One pumping temperature	One pumping temperature
16	#3 High plus outlet water temperature	Triple pumping temperature	Triple pumping temperature	Triple pumping temperature	Triple pumping temperature
17	Triple pumping temperature	#6 Low plus outlet water temperature	#6 Low plus outlet water temperature	#3 High plus outlet water temperature	Second pumping pressure
18	#6 Low plus outlet water temperature	#3 High plus outlet water temperature	#3 High plus outlet water temperature	#6 Low plus outlet water temperature	#6 Low plus outlet water temperature
19	Five pumping temperature	Five pumping temperature	Five pumping temperature	Five pumping temperature	Five pumping temperature
20	#7 Low plus outlet water temperature	#7 Low plus outlet water temperature	#7 Low plus outlet water temperature	#7 Low plus outlet water temperature	#7 Low plus outlet water temperature
21	Reheat pressure	Reheat pressure	Reheat pressure	Reheat pressure	Reheat pressure
22	#3 High plus hydrophobic temperature	#8 Low plus outlet water temperature	#8 Low plus outlet water temperature	#8 Low plus outlet water temperature	#8 Low plus outlet water temperature
23	#8 Low plus outlet water temperature	#3 High plus hydrophobic temperature	#3 High plus hydrophobic temperature	#3 High plus hydrophobic temperature	Seven pumping pressure
24	One pumping pressure	Condensate temperature	Condensate temperature	Condensate temperature	#3 High plus hydrophobic temperature
25	Condensate temperature	One pumping pressure	Seven pumping pressure	#2 High plus hydrophobic temperature	#2 High plus hydrophobic temperature
26	#2 High plus hydrophobic temperature	#2 High plus hydrophobic temperature	#2 High plus hydrophobic temperature	One pumping pressure	Condensate temperature
27	#1 High plus hydrophobic temperature	Seven pumping pressure	One pumping pressure	Seven pumping pressure	One pumping pressure

28	Four pumping pressure	#1 High plus hydrophobic temperature	#1 High plus hydrophobic temperature	#1 High plus hydrophobic temperature	#1 High plus hydrophobic temperature
29	#5 Low plus hydrophobic temperature	#5 Low plus hydrophobic temperature	#5 Low plus hydrophobic temperature	#5 Low plus hydrophobic temperature	#5 Low plus hydrophobic temperature
30	Triple pumping pressure	Four pumping pressure	Four pumping pressure	Four pumping pressure	Four pumping pressure
31	Five pumping pressure	Triple pumping pressure	Triple pumping pressure	Triple pumping pressure	Triple pumping pressure
32	Seven pumping pressure	Five pumping pressure	Five pumping pressure	Five pumping pressure	Five pumping pressure
33	#7 Low plus hydrophobic temperature	#7 Low plus hydrophobic temperature	#7 Low plus hydrophobic temperature	#7 Low plus hydrophobic temperature	#7 Low plus hydrophobic temperature

3.2.1 Main Steam Temperature Sensitivity Analysis. The amount of coal consumption change corresponding to the main steam temperature variation within ±10°C under different working conditions is calculated, as shown in Figure 3.

As can be seen from Figure 4: When the main steam temperature increases, coal consumption decreases, showing a negative correlation law. Under THA conditions, the coal consumption decreases by about 3.27*g/kWh* for every 10°C increase in main steam temperature; under 30% THA conditions, the coal consumption decreases by about 3.10*g/kWh* for every 10°C increase in main steam temperature.

The sensitivity of main steam temperature to coal consumption gradually decreases as the temperature rises: under THA conditions, when the main steam temperature is 556°C

When the main steam temperature is 576°C, the coal consumption decreases by 0.336 *g/kWh* for every 1°C increase; when the main steam temperature is 576°C, the coal consumption decreases by 0.298 *g/kWh* for every 1°C increase.

Under THA conditions, keeping other parameters constant, the sensitivity factor curve is shown in Figure 4 when the main steam temperature is varied.

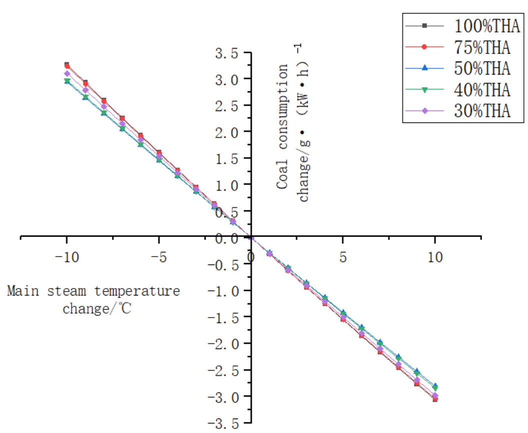

Figure 3. Effect of main steam temperature change on coal consumption

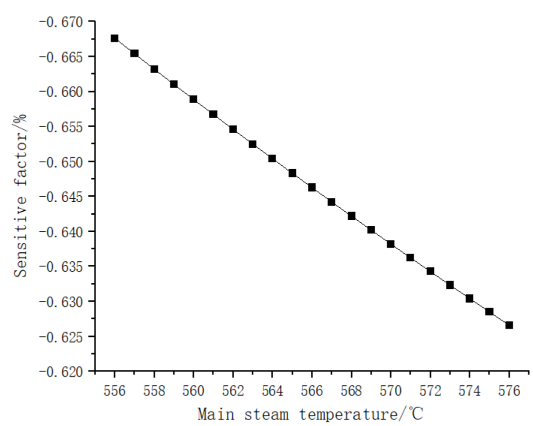

Figure 4. Energy sensitivity curve of main steam temperature under THA conditions

As can be seen from Figure 5: The sensitivity factors of main steam temperature to energy consumption are all negative, indicating that coal consumption decreases as the main steam temperature increases. As the main steam temperature increases, the sensitivity factor gradually decreases, indicating that the energy consumption sensitivity of the main steam temperature decreases with the increase of the main steam temperature.

The sensitivity factor curves of the main steam temperature at different loads are plotted as shown in Figure 5.

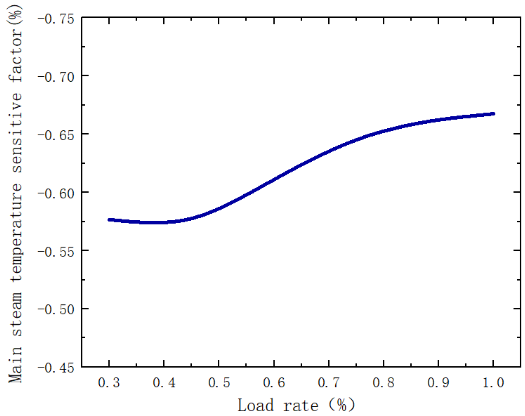

Figure 5. Sensitivity factor curve of main steam on temperature at different loads

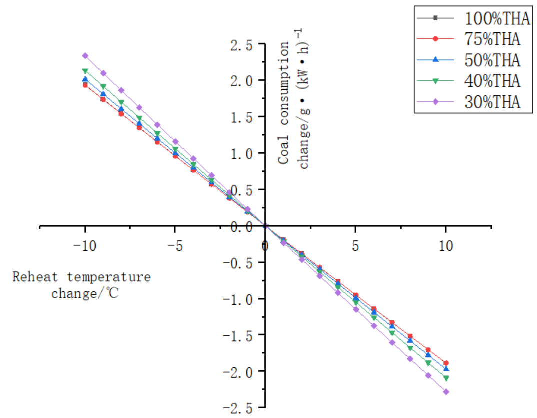

Figure 6. Effect of reheat temperature change coal consumption

It can be seen from Figure 6: the energy consumption sensitivity factor is gradually becoming larger as the load increases, indicating that the main steam temperature is more sensitive to energy consumption at high load conditions.

Optimization measures: lower main steam temperature will cause higher coal consumption, should not make the main steam temperature for a long period of time in a state below the design value; in the main steam temperature is low and in the high load operation state, the main steam temperature on the energy consumption is more sensitive, operation and maintenance should be paid attention to.

3.2.2 Reheat temperature sensitivity analysis. The amount of coal consumption change corresponding to the reheat temperature change in the range of ±10℃ under different working conditions is calculated, as shown in Figure 6.

It can be seen from Figure 7: when the reheat temperature increases, the coal consumption decreases, and there is a negative correlation law. Under THA condition, for every 10℃ increase in reheat temperature, coal consumption decreases by about 1.94 g/kWh ; under 30% THA condition, for every 10℃ increase in reheat temperature, coal consumption decreases by about 2.34 g/kWh . Under the same condition, as the reheat temperature increases, the sensitivity of reheat temperature to coal consumption gradually decreases: under THA condition, when the reheat temperature is 556℃, for every 1℃ increase in reheat temperature, coal consumption decreases by 0.196 g/kWh ; when the reheat temperature is 576℃, the coal consumption decreases by 0.186 g/kWh for each 1℃ increase in reheat temperature.

The sensitivity factor curve is shown in Figure. 7 when the other parameters are kept constant and the reheat temperature is varied under THA conditions.

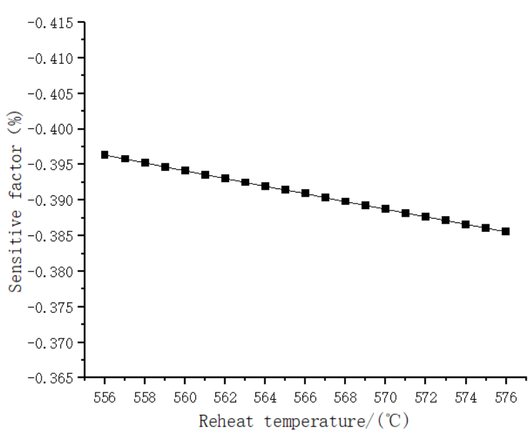

Figure 7. Energy consumption sensitivity curve of reheat temperature under THA working condition

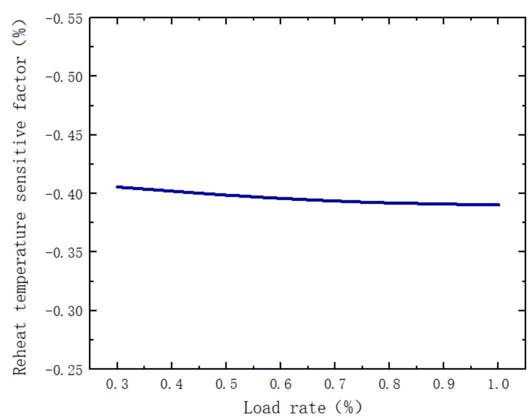

Figure 8. Sensitivity factor curve of reheat temperature under different loads

As can be seen from Figure 8: the sensitivity factors of reheat temperature to energy consumption are all negative, indicating that as the reheat temperature increases

The coal consumption decreases. As the reheat temperature increases, the sensitivity factor gradually decreases, indicating that the energy consumption sensitivity of reheat temperature decreases with the increase of reheat temperature. The sensitivity factor curves of the reheat temperature at different loads are plotted as shown in Figure 8.

It can be seen from Figure 9: With the increase of load, although the energy consumption sensitivity factor tends to decrease, the decrease is not significant.

Optimization measures: The sensitivity of the reheat steam temperature is second only to the main steam temperature. When the reheat temperature rises, coal consumption will be reduced. Try to keep the reheat temperature in line with the main steam temperature, so that it is roughly equal to the design value; when the reheat temperature is relatively low, the sensitivity to energy consumption is stronger, and coal consumption will rise, so try to reduce the reduction of reheat temperature. In the low load condition, the energy consumption sensitivity factor of reheat temperature is slightly higher than that in the high load condition, which should be paid attention to in order to achieve the purpose of energy saving and consumption reduction.

3.2.3 Sensitivity analysis of the second pumping temperature (high-pressure cylinder discharge temperature). The corresponding change in coal consumption within ±10°C of the second pumping temperature change under different working conditions is calculated, as shown in Figure 9.

It can be seen from Figure 10: when the temperature of the second pumping increases, the coal consumption also increases, showing a positive correlation law. In THA working condition

For every 10°C increase in secondary pumping temperature, coal consumption increases by about 2.68 *g/kWh*; for every 10°C increase in secondary pumping temperature, coal consumption increases by about 2.56 *g/kWh* under 30% THA operating conditions.

Under THA conditions, keeping other parameters constant, the sensitivity factor curve is shown in Figure 10 when the second pumping temperature is varied.

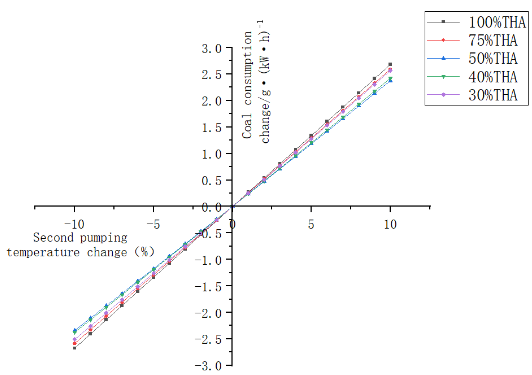

Figure 9. Effect of change in secondary pumping temperature on coal consumption

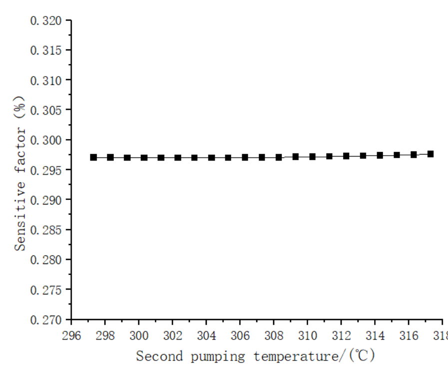

Figure 10. Energy consumption sensitivity curve of the second pumping temperature under THA working condition

It can be seen from Figure 10: The sensitivity factors of the second pumping temperature on energy consumption are all positive, indicating that the coal consumption will gradually increase with the increase of the second pumping temperature. With the increase of the second pumping temperature, the sensitivity factor remains basically the same.

The sensitivity factor curves of the second pumping temperature at different loads were plotted as shown in Figure 11.

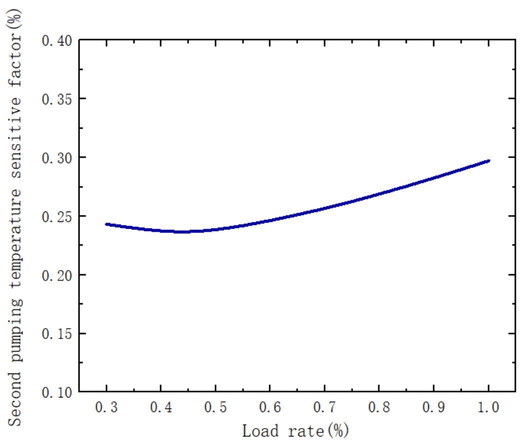

Figure 11. Sensitivity factor curve of the second pumping temperature under different loads

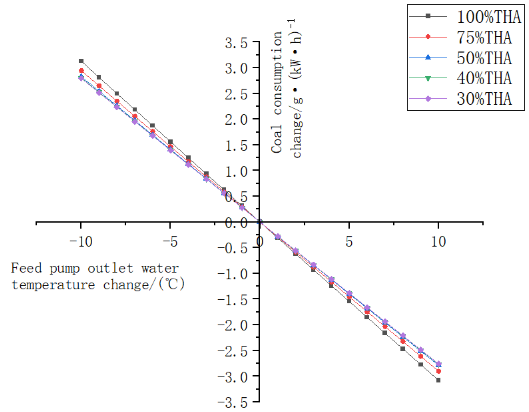

Figure 12. Effect of feed pump outlet water temperature change on coal consumption

From Figure 11, it can be seen that: the sensitivity of the second pumping temperature is small in the low load operation condition, and the sensitivity factor of the second pumping temperature to energy consumption is the largest in the THA condition, i.e. the strongest sensitivity.

Optimization measures: the second pumping temperature, i.e., the high-pressure cylinder discharge temperature, is positively correlated with coal consumption, and when the second pumping temperature increases. It will make the unit coal consumption higher, try to control the second pumping temperature of the floating

The moving range is around its design value; in the high load condition, the energy consumption sensitivity of the second pumping temperature is significantly higher than that of the low load operation condition, and the focus is on the range of the second pumping temperature in the high load operation condition to reduce the coal consumption of the unit.

3.2.4 Feedwater pump outlet water temperature sensitivity analysis. The amount of coal consumption change corresponding to the feed pump outlet water temperature change within ±10℃ under different working conditions is calculated, as shown in Figure 12.

It can be seen from Figure 13: when the feed pump outlet water temperature increases, coal consumption decreases, and there is a negative correlation law. Under THA condition, the coal consumption decreases by about 3.08 *g/kWh* for every 10℃ increase in feed pump outlet water temperature; under 30% THA condition, the coal consumption decreases by about 2.76 *g/kWh* for every 10℃ increase in feed pump outlet water temperature.

Under THA conditions, keeping other parameters constant, when the feed pump outlet water temperature changes, the sensitivity factor curve is shown in Figure 13.

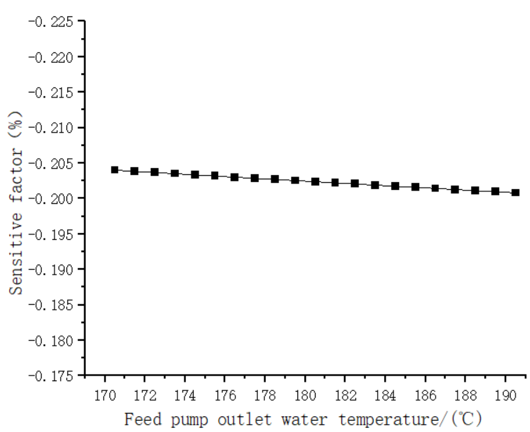

Figure 13. Feedwater pump outlet water temperature energy consumption sensitivity curve under THA working condition

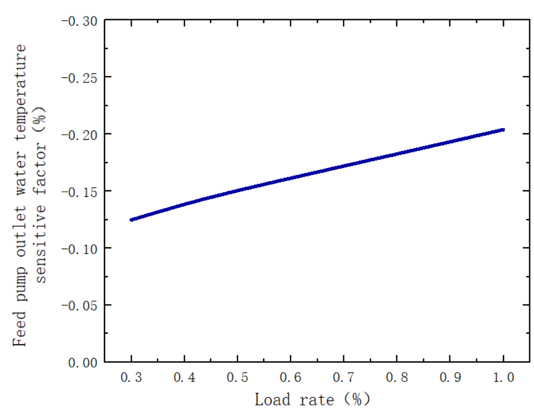

Figure 14. Sensitivity factor curve of feed pump outlet water temperature under different loads

As can be seen from Figure 14: the sensitivity factor of feed pump outlet water temperature to energy consumption is negative, indicating that the change of feed pump outlet water temperature is negatively correlated with the change of coal consumption; with the increase of feed pump outlet water temperature, its sensitivity factor holds a decreasing trend, but the sensitivity factor does not change much.

The sensitivity factor curve of feed pump outlet water temperature at different loads is plotted as shown in Figure 14.

It can be seen from Figure 15: As the load increases, The sensitivity factor of feed pump outlet water temperature gradually increases in.

The feed pump outlet water temperature under THA conditions is the most sensitive to energy consumption.

Optimization measures: As the feed pump outlet water temperature increases, the coal consumption of the unit will be reduced, try not to make the feed pump outlet water temperature below the design value; the energy consumption sensitivity of the feed pump outlet water temperature is stronger in the high load operation condition, so we should focus on the change of the feed pump outlet water temperature in the high load operation condition, which can achieve the purpose of energy saving and consumption reduction.

3.2.5 Six pumping temperature sensitivity analysis. The corresponding change in coal consumption within ±10°C of the six pumping temperatures under different working conditions is calculated, as shown in Figure 15.

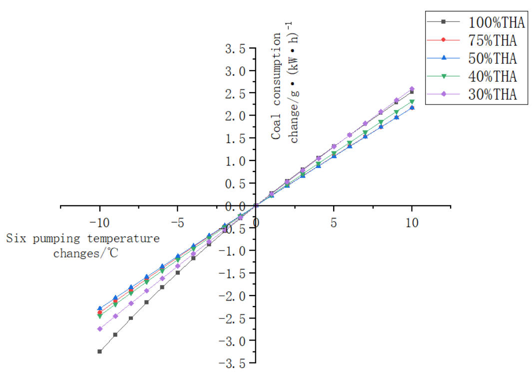

Figure 15. Effect of six pumping temperature changes on coal consumption

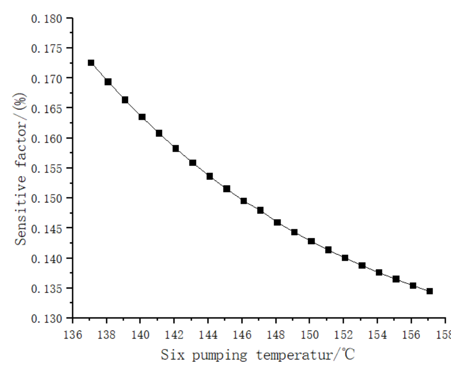

Figure 16. Six pumping temperature energy consumption sensitivity curves under THA conditions

It can be seen from Figure 16: when the temperature of six pumping increases, coal consumption also increases, showing a positive correlation law. Under THA conditions, coal consumption increases by about 3.25 *g/kWh* for every 10°C increase in the temperature of six pumping; under 30% THA conditions, coal consumption increases by about 2.60 *g/kWh* for every 10°C increase in the temperature of two pumping. Under the same conditions, as the temperature of six pumping increases, the coal consumption of six pumping

The sensitivity of temperature to coal consumption gradually decreases: under THA conditions, when the six pumping temperature is 137.1°C, coal consumption increases by 0.379 *g/kWh* for every 1°C increase; when the six pumping temperature is 157.1°C, coal consumption increases by 0.236 *g/kWh* for every 1°C increase in temperature.

Under THA conditions, keeping other parameters constant, the sensitivity factor curve is shown in Figure 16 when the six pumping temperatures are varied.

From Figure 16, it can be seen that: the sensitivity factors of the six pumping temperatures on energy consumption are all positive, indicating that the change of the six pumping temperatures and the change of coal consumption are positively correlated; as the six pumping temperatures increase, their sensitivity factors gradually decrease, indicating that the degree of influence of the six pumping temperatures on energy consumption gradually decreases with the increase of the six pumping temperatures.

The sensitivity factor curves of the six pumping temperatures at different loads were plotted as shown in Figure 17.

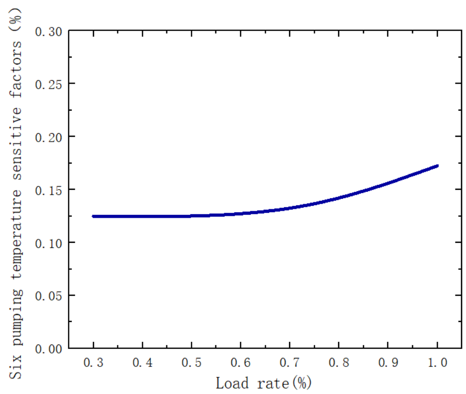

Figure 17. Sensitivity factor curve of six pumping temperatures under different loads

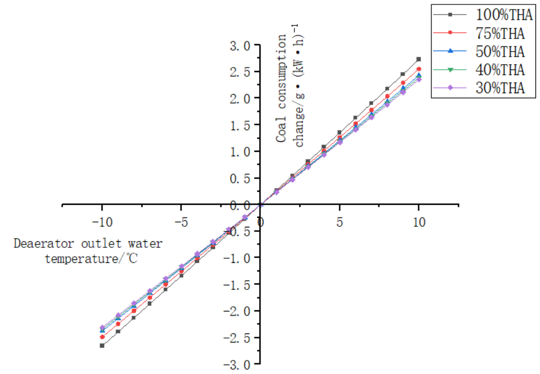

Figure 18. Effect of deaerator outlet water temperature change on coal consumption

As can be seen from Figure 17: the sensitivity factor of six pumping temperatures remains basically constant at 30% THA, 40% THA and 50% THA, and then becomes gradually larger with increasing load, with the strongest sensitivity at THA operating conditions.

Optimization measures: too high temperature of the sixth pumping will increase coal consumption, try to control the temperature of the sixth pumping not too high; the energy consumption sensitivity is stronger when the temperature of the sixth pumping is lower and at high load condition, and should focus on the change of the temperature of the sixth pumping.

3.2.6 Deaerator export water temperature sensitivity analysis. The amount of coal consumption change corresponding to the deaerator outlet water temperature change in the range of ±10°C under different working conditions is calculated, as shown in Figure 18.

It can be seen from Figure 18: When the deaerator outlet water temperature increases, the coal consumption also increases, which is a positive correlation law. Under THA conditions, for every 10°C increase in deaerator outlet temperature, coal consumption increases by about 2.73 *g/kWh*; under 30% THA conditions, for every 10°C increase in deaerator outlet water temperature, coal consumption increases by about 2.35 *g/kWh* .

Under THA conditions, keeping other parameters constant, when the deaerator outlet water temperature changes, the sensitivity factor curve is shown in Figure 19.

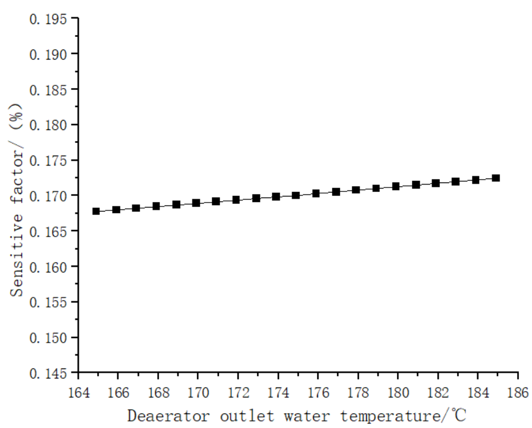

Figure 19. THA operating conditions deaerator outlet water temperature energy sensitivity curve

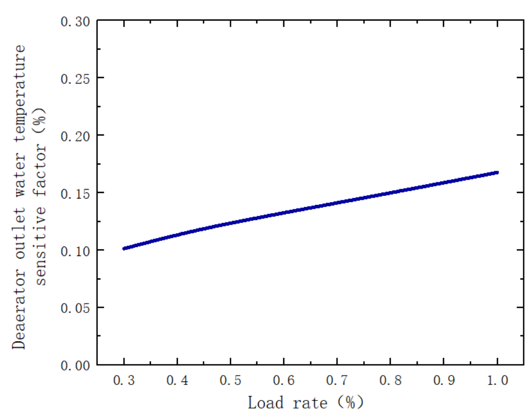

Figure 20. Sensitivity factor curve of deaerator outlet water temperature under different loads

As can be seen from Figure 19: the sensitivity factor of deaerator outlet water temperature on energy consumption are positive, indicating that the change of deaerator outlet temperature is positively correlated with the change of coal consumption; with the increase of deaerator outlet water temperature, its sensitivity factor gradually increases, but the change of sensitivity factor is not large, indicating that the increase of deaerator outlet water temperature does not have much influence on its energy consumption sensitivity.

The sensitivity factor curves of the deaerator outlet water temperature at different loads were plotted as shown in Figure 20.

It can be seen from Figure 20: With the increase of load, the sensitivity factor of the deaerator outlet water temperature gradually increases, indicating that the sensitivity of the deaerator outlet water temperature to energy consumption is stronger in the high load condition.

Optimization measures: Deaerator outlet water temperature and coal consumption are positively correlated, the deaerator outlet water temperature increases, coal consumption increases. Try to control the deaerator outlet water temperature not to be too high, otherwise it will make the unit coal consumption higher. The sensitivity of the deaerator outlet water temperature is obviously higher under high load condition, and the focus should be on the deaerator outlet water temperature under high load condition during operation and maintenance.

4. CONCLUDING REMARKS

(1) In this paper, the sensitivity factor of the measurement point parameters of the turbine unit is calculated by Delphi software programming, and the energy consumption sensitivity intensity of the measurement point parameters is determined by ranking the impact weight of each measurement point parameter on energy consumption.

(2) Paying more attention to the measurement parameters with high sensitivity during the unit operation and maintenance can effectively solve the problems and reduce the coal consumption of the unit, so as to achieve the purpose of energy saving and consumption reduction.

(3) After the sensitivity analysis of the energy consumption of the turbine unit measurement point parameters, it is found that the temperature is more sensitive to the energy consumption, mainly because the temperature has a greater impact on the enthalpy of steam, so the larger energy consumption sensitivity factor under different working conditions is temperature.

(4) When the main steam temperature, reheat temperature, feed pump outlet water temperature and other parameters are higher than the design value, coal consumption will be reduced, but do not make these parameters higher than the design value for a long time, otherwise the unit life will be reduced because the equipment materials are in a high temperature condition for a long time.

(5) The main steam temperature, second pumping temperature (high pressure cylinder discharge temperature), feed pump outlet water temperature, sixth pumping temperature and deaerator outlet water temperature are more sensitive under high load operation condition. In actual operation, focusing on the parameters under high load operation condition can improve the thermal economy of turbine operation.

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