Research on Technical Route Optimization and Energy-saving Characteristics of High-temperature Subcritical Retrofit

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Abstract. In order to further reduce the power supply coal consumption rate for 300MW subcritical units, this paper will conduct a comprehensive analysis to improve the main steam and reheat steam parameters of those units based on the basic principles of thermodynamics, steam turbines and water pumps. The analysis shows that for the subcritical unit retrofit method that only raises the main steam and reheat steam temperature as the basic technical route has better feasibility. On this basis, combined with the actual system and working conditions of the 320MW subcritical unit, a simulation model of the entire plant's thermal system is established for calculation and analysis. The calculation results show that the heat consumption rate of the high-temperature subcritical retrofit can reach 7526.7kJ/kWh. Combined with China Resources Xuzhou #3 unit high temperature subcritical comprehensive retrofit project (using high temperature subcritical transformation and equipped with special energy saving transformation), A comprehensive analysis of the performance of the unit after retrofit. The analysis shows that the coal consumption rate after the retrofit is reduced by 36g/kWh.

1 Introduction

Under the trend of global warming, the coal power industry, is sustain great pressure to reduce emissions[1]. Considering China's special energy structure, even in the future for a long time, coal power will still occupy the main position[2]. In order to further improve the efficiency of coal-fired power plants, the National Energy Administration and other three ministries issued a document named the "Six Year Action Plan" in 2014, which required that the annual average power consumption of coal-fired units with a capacity of 300MW should be less than 310g/kWh[3]. However, the actual annual average coal consumption of most 300MW subcritical units is about 340g/kWh[4]. In the face of a large number of 300MW subcritical units[5], which have better economic benefits in the grid peak regulation, it is obviously unreasonable to shut down all the units. Thus, high efficiency retrofit is necessary for these subcritical units.

At present, domestic and foreign research institutions have carried out more research on the retrofit of subcritical units. The efficiency of the turbine can be increased by 2%~2.6% after the whole turbine has been reformed by Hitachi[6]. During the period from 2007 to 2012 in China, the early 300MW grade turbines put into production have been large scale flow path retrofit[7]. However, for the subcritical turbine flow path retrofit project, the domestic turbine manufacturers generally have the prominent problems that the turbine efficiency

declines rapidly[8-9]. Subcritical cross-generation retrofit technology; domestic scientific research institutes have a certain theoretical research[10 -11].

The existing retrofit solution of subcritical units are mostly divided into three kinds. First, power cycles the system optimization, such as the steam turbine flow path retrofit; Second, the "double lift" retrofit of the initial parameters, such as the upgrade parameter retrofit; Third, Rankine cycle optimization, such as secondary reheat retrofit. There are few "single-lift" modifications of initial and reheat parameters, especially retrofit that only increase the main steam and reheat steam temperature.

Based on thermodynamics, basic principles, this paper analyzes the feasibility of the "single lift" retrofit, and combined with the actual case unit simulation. The results show that the heat consumption rate of the high temperature subcritical transformation can reach 7526.7kJ/kWh based on the technical route of only increasing the temperature of main steam and reheat steam. Combined with the case analysis of China Resources Xuzhou example high-temperature subcritical comprehensive retrofit (Adopt high temperature subcritical retrofit, and equipped with special energy-saving transformation), the coal consumption rate decreases by 36g/kWh after transformation, and the coal consumption rate can reach 281.95g/kWh.

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2 TO IMPROVE THE SENSITIVE AND FEASIBILITY ANALYSIS OF MAIN STEAM AND REHEAT STEAM PARAMETERS

2.1. Influence on relative internal efficiency of steam turbine

2.1.1 Improve the influence of main steam pressure on internal efficiency

Steam leakage loss at the top of steam turbine[12] can be expressed as:

$$\delta h_t = \frac{\mu_1 \overline{\delta_z} \psi_t}{\mu_2 \sin \alpha_1} \Delta h_1 ' \tag{1}$$

Where δh_t is steam leakage loss at the top of moving-blade; $\overline{\delta_z}$ is ratio of tip axial clearance δz to moving-blade height lb; ψ_t is reaction Ω_m and seal tooth of the average diameter d_b/l_b related empirical coefficient; μ_1 is an empirical coefficient related to δz and the thickness of the girth edge Δs; μ_2 is an empirical coefficient related to δ_z and speed ratio u/c_a; α_1 is nozzle outlet steam flow angle; $\Delta h_1'$ is effective specific enthalpy drop at the stage without steam leakage loss.

It can be seen from Equation (1). The tip loss δh_t is strongly correlated with the reciprocal $1/l_b$ of blade height. When the subcritical main steam pressure of 16.7MPa is increased to 26MPa, the volumetric flow rate decreases by 40.8%, the blade height of the inlet side of the high-pressure cylinder of the steam turbine decreases accordingly, the steam leakage loss increases, and the relative internal efficiency of the steam turbine decreases.

For 300MW grade subcritical steam turbine, the mass flow of main steam is small, and the blade on the inlet side is short. In this capacity class unit, the stage efficiency decline caused by end loss is very sensitive to the blade height. When the pressure increases substantially, the blade shortens correspondingly, the ratio of end loss increases significantly, and the relative internal efficiency of the turbine decreases.

In addition, steam turbine moisture loss can be expressed as[12]:

$$\delta h_x = (1 - x_m) \Delta h_i ' \tag{2}$$

Where δh_x is moisture loss; $\Delta h_i'$ is effective specific enthalpy drop at stages without moisture loss; and x_m is average steam dryness within the stage.

$$x_m = \frac{s_x - s'}{s'' - s'} \tag{3}$$

Where s_x is the exhaust steam entropy; s" is entropy of dry saturated steam at exhaust pressure; s' is entropy of saturated water at exhaust pressure.

When the main steam pressure increases and the reheat steam pressure increases correspondingly, the exhaust steam dryness decreases, the low-pressure cylinder moisture loss increases, and the low-pressure cylinder efficiency decreases accordingly.

2.1.2 Improve the influence of main steam and reheat steam temperature on internal efficiency

When the main steam and reheat steam temperature is raised to 600℃, the volume flow increases by 11.7%, and the blade height at the inlet side of the turbine increases accordingly. The relative internal efficiency of the turbine is improved.

In addition, the reheat steam temperature increases, the steam turbine exhaust dryness increases, the low-pressure cylinder moisture loss is reduced, the low-pressure cylinder efficiency is improved.

2.2. Comprehensive feasibility analysis of improving main steam parameters

For 300MW class units, the main steam temperature is kept constant and the main steam pressure is increased. Although the circulation efficiency increases, the relative internal efficiency of the turbine decreases. At the same time, related to the pressure of other equipment need comprehensive change, the cost performance is very low.

But, increasing the main steam temperature and reheat steam temperature alone will increase the cycle efficiency and bring additional benefits to the internal efficiency of steam turbine. In addition, the main steam and reheat steam pressure is unchanged, can maximize the use of the original system. Therefore, the retrofit method that only increases the main steam and reheat steam temperature as the basic technical route has better feasibility.

3 Superiority analysis of high temperature subcritical retrofit

For 300MW subcritical unit, it is more feasible to improve the temperature of main steam and reheat steam. The high temperature subcritical retrofit scheme is put forward on this basis, and its technical route is: The temperature of the main steam and reheat steam of the boiler is raised to 600℃ of the current ultra-supercritical level through the retrofit of the superheater and reheater, keeping the pressure unchanged, and the steam turbine has been retrofit into high temperature and high efficiency.

3.1. The advantage analysis only considers the improvement of cycle efficiency

Combined with the actual operating conditions of a 320MW unit, the energy saving characteristics of the high temperature transformation were analysed and calculated. The basic idea is to use MATLAB programming software to establish the calculation model of the whole plant's thermal system based on the working conditions before the retrofit of the case unit[13]. On this basis, the parameters of main steam and reheated steam were gradually increased (only the influence of increasing parameters on cycle efficiency was considered), and the gains of specific heat consumption and net efficiency under pressure and temperature

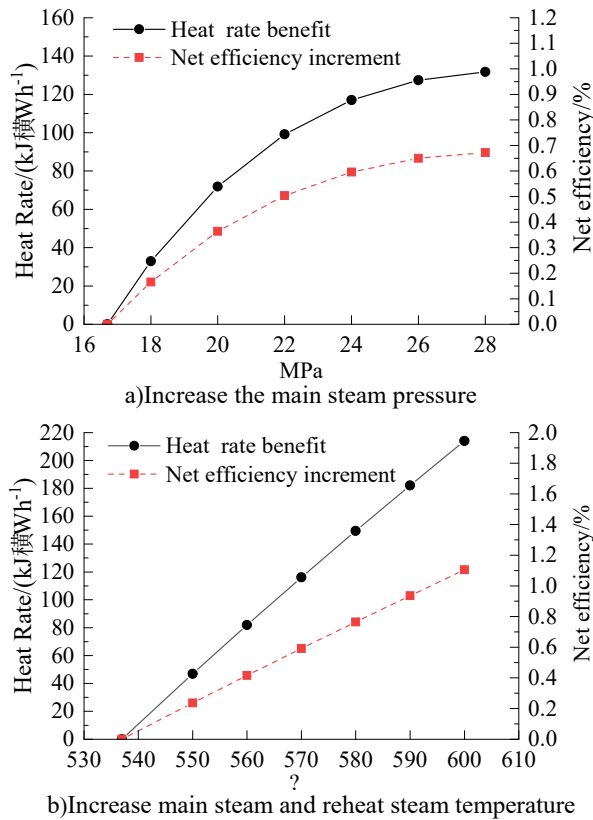changes were obtained respectively, and the calculation results were shown as Fig. 1follows:

a)Increase the main steam pressure

b)Increase main steam and reheat steam temperature

Fig. 1 Improve main steam and reheat steam parameters

Fig. 1 a) shows that when the main steam pressure increases from 16.7MPa to 26MPa, the benefit increment of unit specific heat consumption gradually converges, and the net efficiency of the unit only increases by about 0.65%. As can be seen from Fig. 1(b), when the main/reheat steam temperature increases from 537°C to Table **1**:

600°C, the unit efficiency gains increase linearly and the net efficiency increases by more than 1%.

3.2. Advantage analysis considering internal efficiency change and thermodynamic system optimization

In fact, due to the major steam and reheat steam temperature increase, the steam turbine flow part must be replaced, equivalent to the flow path retrofit.

In addition, the internal efficiency benefit by the high temperature and high efficiency retrofit of steam turbines include two aspects: First, it is equivalent to the internal efficiency benefit obtained by the traditional flow transformation; Second, high temperature steam turbine additional efficiency improvement.

Besides, in order to cooperate with the heating retrofit of the boiler, it is necessary to increase the feed water temperature, so the first stage high pressure heater is added, thus further improving the average heat absorption temperature of the boiler and the net efficiency of the unit.

By means of modelling and simulation, the energy saving characteristics of turbine internal efficiency improvement and adding high pressure heater are analysed. The calculation idea is to establish a thermodynamic system calculation model of the whole plant, which only increases the main steam and reheat steam temperature to 600°C (considering only the influence on cycle efficiency). On this basis, the internal efficiency increments of the turbine which is equivalent to that obtained by the traditional through-flow modification is considered first; In addition, the internal efficiency of the turbine is improved due to the heating; Finally, consider the effect of increasing feed water temperature on unit efficiency. Simulation results are as follows

Table 1 Simulation results

Item	high temperature subcritical retrofit			
	The main/reheat steam temperature is raised to 600°C	High temperature retrofit and high efficiency retrofit of steam turbine flow part		Raise feed temperature
		Equivalent to traditional flow retrofit	Additional benefits of high temperature	
Heat rate (kJ·kWh⁻¹)	7944.3	7757.8	7602.2	7526.7
Net efficiency /%	39.42	40.6	41.61	42.06
Net efficiency benefit /%	1.02	2.2	3.21	3.66
Net efficiency increment /%	1.02	1.18	1.01	0.45

Note: the net efficiency of 300MW subcritical unit under rated working condition is 38.4% as the benchmark.

As can be seen from Table **1**, if the internal efficiency benefit of equivalent conventional flow retrofit are not included, the comprehensive net efficiency benefit of turbine's high-temperature transformation are 2.48%, while the

net efficiency gain is 3.66% after taking this into account. The net efficiency of 600°C heating retrofit can reach 42.06% (coal consumption of power supply is 292g/kWh).

4 Example analysis of high temperature subcritical retrofit

The Unit 3 of China Resources Power (Xuzhou) Co., Ltd Tongshan Power Plant was put into operation in 2004. In 2012, HP-IP turbine flow paths modification, and in 2017, the performance test was carried out. In addition to the heating retrofit, the project also loaded a series of special energy-saving technical retrofit[14]. The result is shown in Fig. 2:
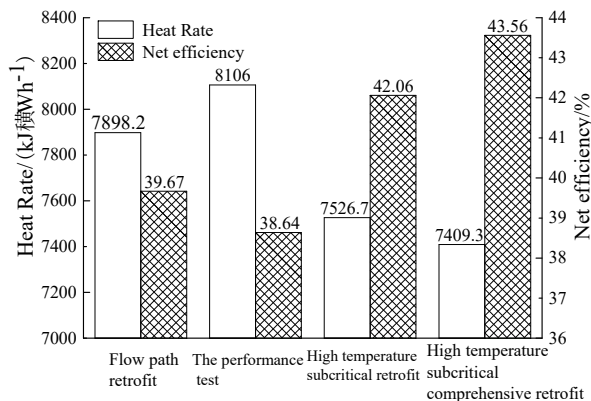

Fig. 2 Calculation and test results

As can be seen from Fig. 2, the net efficiency of the unit has decreased by 1.03% after 5 years of operation after the HP-IP turbine flow paths modification. The performance test shows that the net efficiency is 43.56 % and the coal consumption of power supply is 281.95g/kWh under the rated working condition after the modification. Compared with the performance test before the 2017 retrofit, the net efficiency increased by 4.94% and the coal consumption decreased by 36g/kWh. If the unit is not reformed by flow, the coal consumption will decrease by more than 40g/kWh.

5 conclusion

(1) Due to the increase of main steam temperature, the heat consumption of 300MW steam turbine can reach 7526.7kJ/kWh. After loading a series of energy-saving technologies, the power supply coal consumption rate of 320MW subcritical unit is lower than 282 g/kWh under rated working conditions.

(2) If the high-temperature subcritical retrofitting technology can be fully applied in China, the annual energy saving will be more than 58 million tons of standard coal, emission reduction of carbon dioxide will be more than 156 million tons, according to the estimate of the energy saving of a single unit of at least 35g/kW.

Acknowledgments

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