Energy Consumption Analysis of Deep Peak Regulation in a 300MW Plant With Subcritical Steam Drum Furnace

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Abstract. Based on the operation and energy consumption calculation data of 300MW subcritical steam drum furnace in a plant, the energy consumption variation characteristics of the unit under various working conditions were analyzed. It was found that the coal consumption of the unit was about 40g/kWh higher than the rated load during low load peaking operation. The boiler efficiency was not significantly reduced during low-load operation, but the main and reheat steam temperatures were significantly reduced, resulting in a significant decrease in the efficiency of the high and medium pressure cylinders of the turbine. In addition, the analysis found that high auxiliary power consumption rate was also an important factor affecting low load energy consumption during low load operation.

1. Introduction

As many outside power plants settle in Shandong, with the increase of the amount of power generated by renewable energies such as wind and photovoltaic power, the peaking regulation pressure of Shandong Power Grid has been increasing. In order to improve the peaking regulation capacity of the power system and promote the consumption of renewable energies, the Energy Bureau issued “Shandong Power Auxiliary Service Market Operation Rules”, requiring the power plants to participate in the grid-assisted peaking regulation service in a competitive manner. The deep peak regulation interval of the unit is often the interval with higher energy consumption of the unit. However, the technicians of the power plant do not have an accurate understanding of the energy consumption value during the deep peak adjustment of the unit, which brings difficulties to the peak regulation of the unit and causes the failure to accurately evaluate the economics of flexibility transformation, which is not conducive to the rational promotion of flexibility transformation.

Among all the units in our province, the number of 300MW units is the largest, and the energy consumption variation characteristics of this type of unit participating in deep peak regulation are studied, which is of great significance to guide the unit to carry out corresponding flexibility transformation and peak regulation.
2. Equipment overview
In a power plant, unit #1, #2 boiler is a SG-1036/17.5-M882 subcritical pressure primary intermediate reheat control circulating steam drum furnace manufactured by Shanghai Boiler Factory, which uses an oscillating burner, a four-corner arrangement, and tangential combustion. Single furnace, [Ⅰ] type open-air layout, all-steel frame suspension structure, balanced ventilation, solid-state slagging. Three British TAYLER low-pressure boiler circulating pumps are arranged in front of the furnace, and two three-point warehouse-type air preheaters are arranged at the rear of the furnace. The boiler milling system is a double-inlet and out steel ball mill with a positive pressure and a direct-blowing type. The two coal mills have a total of four primary air nozzles.

The steam turbine is a subcritical, intermediate reheat, high and medium pressure cylinder, combined cylinder, twin-cylinder double-exhaust steam, single-shaft, condensing steam turbine produced by Shanghai Steam Turbine Factory.

In order to study the change of energy consumption of the unit under deep peaking regulation and normal operation, we calculated, counted and analyzed the energy consumption of the unit under 26 working conditions. The energy consumption calculation method is based on GB/T 10184-2015 and GB8117-2008, and the main stream flow rate is corrected by using the data in the performance test.

3. Analysis of Energy Consumption

3.1. Analysis of Boiler Efficiency
The boiler efficiency of the unit under 26 working conditions is shown in Figure 1. The boiler efficiency above 60% load is about 92.5%, and the boiler efficiency below 40% load is about 90%, which shows that the boiler efficiency is relatively high. The boiler exhaust temperature decreases slightly with load decrease. The carbon content of the fly ash and slag of the boiler can be kept stable with the change of load, which can be maintained at 1.2% and 1.5%, respectively, as shown in Figure 2. In the 7 operating conditions of low load 111MW (33.64% rated capacity), the carbon content of fly ash fluctuated between 1.15 and 1.32%, and the carbon content of large slag fluctuated between 1.52 and 1.85%, indicating that the unit participated in the case of deep peaking regulation, the combustion inside the boiler is relatively sufficient, and there is no case where the carbon content of the ash is greatly increased.

![Figure 1. The boiler efficiency of the unit under 26 working conditions.](image-url)
3.2. Analysis of Steam Turbine Heat Rate

It can be seen from Figure 3 that the heat rate of the turbine increases with the load decrease. Figure 4 and Figure 5 are comparisons of efficiency and design values of high-pressure and medium-pressure cylinders. It can be seen from Figure 5 that the efficiency of the high-pressure cylinder is much lower than the design value at low load, and the lower the load, the larger the deviation. The same problem exists in the efficiency of the medium pressure cylinder. The high and medium pressure cylinder efficiency is positively correlated with the main steam temperature and the reheat steam temperature. Due to the low load, the main steam temperature and the reheat steam temperature are difficult to maintain at the rated value of 545°C, as shown in Figure 6, resulting in a decrease in the efficiency of the high and medium pressure cylinders, which in turn leads to an increase in heat consumption at low load.

Figure 2. The carbon content of the fly ash and slag of the boiler under 26 working conditions.

Figure 3. The heat rate of the unit under 26 working conditions.
Figure 4. Comparisons of efficiency and design values of high-pressure cylinders.

Figure 5. Comparisons of efficiency and design values of medium-pressure cylinders.

Figure 6. The main steam and reheat steam temperature of the unit under 26 working conditions.
3.3. Analysis of Plant Service Power Rate

It can be seen from Figure 7 that the plant service power rate is much higher at the high load than that at low load, the plant service power rate is about 5% when the load is above 300MW, while it is about 8% when the load is 160MW, and it is as high as 9.5% when the load is 110MW. The difference between high and low load is nearly doubled.

![Figure 7. Change of auxiliary power consumption rate.](image)

### Table 1. Consumption of Rotating Equipment.

| Active Power MW | Power Consumption of MILL % | Power Consumption of FAN % | Power Consumption of PUMP % | Unite Consumption of MILL % | Unite Consumption of FAN % | Unite Consumption of PUMP % |
|----------------|-----------------------------|---------------------------|-----------------------------|-----------------------------|---------------------------|---------------------------|
| 111.50         | 1.11                        | 2.96                      | 1.49                        | 20.01                       | 14.81                     | 3.73                      |
| 111.50         | 1.08                        | 3.04                      | 1.48                        | 19.27                       | 15.72                     | 3.85                      |
| 111.62         | 1.17                        | 3.18                      | 1.59                        | 23.89                       | 17.09                     | 4.27                      |
| 111.26         | 1.09                        | 3.06                      | 1.48                        | 21.04                       | 16.28                     | 3.89                      |
| 111.33         | 1.20                        | 3.36                      | 1.60                        | 22.01                       | 18.24                     | 4.14                      |
| 111.43         | 1.17                        | 3.24                      | 1.59                        | 25.01                       | 18.95                     | 4.21                      |
| 111.25         | 2.00                        | 3.08                      | 1.48                        | 37.70                       | 16.91                     | 3.95                      |
| 125.34         | 1.04                        | 3.08                      | 2.63                        | 19.05                       | 18.32                     | 7.37                      |
| 134.98         | 0.96                        | 2.84                      | 2.44                        | 19.15                       | 16.98                     | 6.78                      |
| 135.37         | 0.94                        | 2.60                      | 1.25                        | 19.97                       | 14.43                     | 3.22                      |
| 139.50         | 0.93                        | 2.85                      | 2.36                        | 18.95                       | 18.18                     | 6.77                      |
| 160.35         | 1.52                        | 2.26                      | 1.04                        | 32.54                       | 13.46                     | 2.82                      |
| 160.36         | 1.54                        | 2.29                      | 1.04                        | 29.12                       | 13.01                     | 2.78                      |
| 165.37         | 1.57                        | 2.35                      | 1.09                        | 43.12                       | 14.54                     | 2.99                      |
| 200.44         | 1.31                        | 1.95                      | 0.68                        | 26.76                       | 11.25                     | 1.73                      |
| 210.53         | 1.16                        | 1.97                      | 0.81                        | 27.71                       | 12.42                     | 2.12                      |
| 230.65         | 1.14                        | 2.06                      | 2.57                        | 26.38                       | 12.99                     | 4.11                      |
| 229.37         | 1.12                        | 1.99                      | 0.60                        | 21.93                       | 11.06                     | 1.53                      |
| 270.32         | 0.99                        | 2.02                      | 0.73                        | 24.77                       | 13.08                     | 1.89                      |
| 268.85         | 0.99                        | 2.19                      | 0.74                        | 19.60                       | 12.94                     | 1.87                      |
| 301.16         | 0.91                        | 1.81                      | 0.64                        | 21.35                       | 10.86                     | 1.71                      |
| 301.28         | 0.91                        | 1.93                      | 0.63                        | 20.99                       | 12.22                     | 1.69                      |
| 328.98         | 0.78                        | 2.08                      | 1.12                        | 17.34                       | 13.27                     | 3.16                      |
| 329.31         | 0.83                        | 2.04                      | 0.63                        | 18.23                       | 12.49                     | 1.66                      |
| 329.50         | 0.76                        | 1.92                      | 0.49                        | 15.04                       | 10.65                     | 1.21                      |
| 331.20         | 0.80                        | 2.06                      | 1.09                        | 17.12                       | 12.40                     | 3.15                      |
It can be seen from Table 1 that except for the coal mill, the unit consumption of other rotating equipment does not change much, and the power consumption rate increases significantly. This is because the power generation is small at low load, but the energy consumption of the rotating equipment is not equally decreased, resulting in an increase in power consumption. Coal mill unit consumption and milling unit consumption are the largest at 160 MW load because it is the critical load for double-grinding and single-grinding operations.

3.4. Energy Consumption Change

It can be seen from Figure 8 that the net coal consumption rate is about 325g/kWh when the load is above 300MW. The net coal consumption rate is about 350g/kWh when the load is 160MW. The net coal consumption rate is about 360g/kWh when the load is 110MW. It can be seen from the above analysis that the increase in net coal consumption rate is mainly due to the increase in heat rate of the turbine and the fact that auxiliary power consumption rate does not decrease in equal proportion with the decrease of load.

![Figure 8. Change of the net coal consumption rate.](image)

4. Conclusion

This paper analyzed and compared the energy consumption of a 300MW unit under a plurality of working conditions, and found that the net coal consumption rate of the unit was significantly reduced when the load is low, which is about 40g/kWh higher than the rated load. The combustion situation in the furnace is still good at low load, the decrease of boiler efficiency is not obvious, but the main steam temperature and reheat steam temperature are obviously reduced, which leads to a large decrease in the efficiency of the high and medium pressure cylinders of the turbine and an increase in the heat consumption of the turbine. When the load is low, the relatively high auxiliary power consumption rate of the plant is also an important factor affecting the energy consumption.

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