Adjustment and research on the nozzle governing ultra-supercritical unit's operation mode

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Abstract. The mixed-valve sequence of an ultra-supercritical steam turbine designed by the manufacturer is only applicable to basic load. The best initial steam pressure corresponding to the different load under the sequence-valve sequence is determined by field optimization test, which can improve the operating economy and the frequency-modulation response capability under partial load.

1. Preface
Because of the gap between the peak-valley of power demand, the turbine generator unit has long been in the variable-load operation condition. The choice of the operation mode of the steam turbine under partial load is directly related to the thermal economy and safety of the unit. A power plant No.2 steam turbine manufactured by Orient Steam Turbine Co., Ltd. is N660-25 / 600/600 ultra-supercritical condensing steam turbine. The Steam distribution mode designed by the manufacturer is the mixed-valve sequence (Figure 1), which has a good economic benefits when the load is greater than 80%; but in the low-load operating condition, the valve sequence is not conducive to the unit operating economy and the frequency-modulation response capability. At the request of the power plant, the manufacturer added a set of sequence-valve sequence (Figure 2), and the two valve sequences can switch online. Subsequently, the field optimization test was carried out on Unit 2, which determines the best initial steam pressure corresponding to the different load under the new valve sequence.

2. Analysis of the steam flow characteristic
The difference of the steam distribution mode and the operation mode affects the variable operating condition of the steam turbine. No.2 steam turbine adopts the nozzle governing distribution mode, its four high-pressure regulating valves correspond to four groups of nozzles. Among them, The GV1/GV3 valves correspond to the lower two groups of nozzle group, The GV2/GV4 valves correspond to the upper two groups of nozzle group. The manufacturer recommends that the unit operates in the "fixed-sliding-fixed" compound operation mode.
Figure 1 shows the flow characteristic of the mixed-valve sequence. For the mixed-valve sequence, when the flow demand is less than 87%, the high pressure valve will be in the throttling state, and the greater the flow demand deviates, the greater the throttling loss is. In the actual operation, the flow demand should avoid less than 87%; when the flow demand is greater than 87%, the initial steam pressure will soon fall off the critical pressure range with the load drop. Although the throttling loss reduces, the ideal cycle thermal efficiency and the frequency-modulation response capability will reduce too much. According to the design of the manufacturer, when the flow demand is 87% under the rated parameters, the unit reached 660MW rated power, and the flow demand is the best flow demand for No.2 steam turbine. At the same time, the mixed-valve sequence is very suitable for the starting condition and the shut-down condition for the unit.

Figure 2 shows the flow characteristics of the sequence-valve sequence. The GV1/GV3 valves corresponding to the lower two groups of nozzle group first open simultaneously in order to ensure security of the governing stage; when the flow demand increases, the GV2 valve and the GV4 valve opens in turn.
Only in terms of economy, for the sequence-valve sequence, the unit operation is no longer limited to the three-valve sliding pressure (the flow demand is 87%); it can also use two-valve sliding pressure under the low-load operating condition (the flow demand is 68%). On the one hand, the throttling loss of high-pressure valve can reduce; on the other hand, the initial steam pressure can be lifted. Therefore, the sequence-valve sequence not only retains the advantages of the good economic benefits of the high-load operating condition of the mixed-valve sequence, but also provides possibility of increasing the cycle thermal efficiency of the unit under the low-load operating condition. However, it must be pointed out that the sequence-valve sequence does not apply to the starting condition and the shut-down condition.

3. Optimization test and analysis

If it is considered simply from the perspective of thermal economy, the unit is not allowed to use sliding pressure operation when the initial pressure is below the critical pressure. [1] Under the four-valve fully opened mode, although the relative internal efficiency of high-pressure cylinder can increase by from 1.0% to 1.5%, but the cycle heat efficiency will be greatly reduced, and the frequency-modulation response capability of the unit will be lost. In the sliding pressure operation condition, fully opening all the governing valves is not the only way, fully opening part of the governing valves may be more economical. [2]

The global dynamic optimization tests method [3] applies to the field optimization test of Unit 2. According to the preliminary test data of the global dynamic optimization test, three typical operating conditions were selected. Then the conventional thermal performance tests were carried out, and the corrected heat rate was the test result of each operating condition.

3.1 The result of optimization test

Table 1. The economic comparison of sequence-valve sequence and mixed-valve sequence

| Item                                | Mixed-valve sequence condition | Sequence-valve sequence condition |
|-------------------------------------|--------------------------------|-----------------------------------|
| Electrical power (kW)               | 540746                         | 538048                           |
| Initial steam pressure (MPa)        | 23.80                          | 20.91                            |
| Corrected heat rate (kJ/(kW.h)^{-1})| 7630.70                        | 7597.29                          |
| Corrected heat rate difference (kJ/(kW.h)^{-1}) | 33.41                  |                                    |
| Coal consumption rate difference (g/(kW.h)^{-1}) | 1.31                     |                                    |
| 480MW                               | 478800                         | 478892                           |
| Initial steam pressure (MPa)        | 20.78                          | 22.04                            |
| Corrected heat rate (kJ/(kW.h)^{-1})| 7712.82                        | 7679.50                          |
| Corrected heat rate difference (kJ/(kW.h)^{-1}) | 33.31                  |                                    |
| Coal consumption rate difference (g/(kW.h)^{-1}) | 1.31                     |                                    |
| 420MW                               | 419976                         | 420230                           |
| Initial steam pressure (MPa)        | 18.56                          | 21.05                            |
| Corrected heat rate (kJ/(kW.h)^{-1})| 7808.85                        | 7740.20                          |
| Corrected heat rate difference (kJ/(kW.h)^{-1}) | 68.65                  |                                    |
| Coal consumption rate difference (g/(kW.h)^{-1}) | 2.69                     |                                    |
| 360MW                               | 360407                         | 363684                           |
| Initial steam pressure (MPa)        | 15.31                          | 18.03                            |
| Corrected heat rate (kJ/(kW.h)^{-1})| 7966.66                        | 7898.49                          |
| Corrected heat rate difference (kJ/(kW.h)^{-1}) | 68.17                  |                                    |
| Coal consumption rate difference (g/(kW.h)^{-1}) | 2.67                     |                                    |
| 300MW                               | 299005                         | 308098                           |
| Initial steam pressure (MPa)        | 13.34                          | 15.74                            |
| Corrected heat rate (kJ/(kW.h)^{-1})| 8215.69                        | 8141.08                          |
| Item                                      | Mixed-valve sequence condition | Sequence-valve sequence condition |
|------------------------------------------|--------------------------------|----------------------------------|
| Corrected heat rate difference \(\text{kJ}(\text{kW} \cdot \text{h})^{-1}\) | 74.61                          |                                  |
| Coal consumption rate difference \(\text{g}(\text{kW} \cdot \text{h})^{-1}\)  | 2.93                           |                                  |

From Table 1, according to the optimization test, under the 540MW ~ 300MW operating condition, the corrected heat rate decreases by an average of 55.63kJ / (kW.h), equivalent to coal consumption rate reduced by 2.18g / (kW.h). At the same time, under the 480MW ~ 300MW operating condition, the initial steam pressure after optimization is higher than that of the mixing valve sequence by 2.22MPa, which improves the frequency-modulation response capability of the unit under partial load.

### 3.2 The recommended operation mode

According to the result of optimization test, the recommended operating mode of unit 2 runs the following steps:

1. In the 200MW ~ 440MW operating condition, the flow demand should be set to 68%; Unit 2 maintains two-valve sliding pressure operation mode;
2. In the 440MW ~ 540MW operating condition, the initial steam pressure should be set to 22.0MPa avoiding damaging the unit due to the initial steam pressure beyond 22.5MPa; The flow demand increases gradually from 68% to 87%;
3. In the 540MW ~ 630MW operating condition, the flow demand should be set to 87% ; Unit 2 maintains three-valve sliding pressure operation mode;
4. In the 630MW ~ 740MW operating condition, the initial steam pressure should be set to the rated pressure; Unit 2 maintains constant pressure operation mode.

### 4. Conclusion

The mixed-valve sequence has the good economic benefits in more than 80% load, but it does not apply to partial load. The sequence-valve sequence not only improves the efficiency of the unit and the frequency-modulation response capability, but also can exchange safely with the mixed-valve sequence online. It brings the economic and security on the double benefits to the power plant.

### Reference:

[1] Shen Shi Yi: steam turbine principle [M]. Beijing: China power press, 1998: 163.
[2] Jiang Ling, Cao Zhu Qing: The best way to look at the running of the steam turbine from the economy[J], Shanghai steam turbine, 2002, (1): 36-42.
[3] Wang Zhong Hai, Yan Tao, etc. Large steam turbine transformer runs the global optimization test method, Thermal power generation, 2013, 42(7): 100-104.