Technical and economic analysis of the coupling of optical axis heat supply and thermal storage peaking of 200 MW unit

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Abstract. Based on two 200MW three-cylinder and three-exhaust steam condensing units, the economic analysis of the unit connected pipe extraction, optical shaft heating and heat storage technology is carried out. Through these analyses, the coupling of the Optical shaft heating and the heat storage technology can not only give full play to the heating capacity of the unit, but also realize the “thermoelectric decoupling” and improve the flexibility of thermal power. Under certain external heat load demand, the power generation load can be reduced to 88MW when optical axis heating (only 44% of rated load). Besides, there is an optimal combination scheme. The annual policy subsidy is up to 424 million Yuan and the investment recovery period of the project is 5.6 years. The economic benefit of this project is obvious. It is recommended that the technology be applied to areas with a peak grid subsidy policy.

1. Foreword
At present, the traditional thermal power industry has a large problem of overcapacity, while clean energy has the problem of abandoning wind and abandoning light. To alleviate the above contradictions, some local governments have introduced a power grid peaking policy to encourage and supervise power plants to implement power peak shaving. However, the basic principle of operation based on “heat setting” makes the power peaking capacity of cogeneration units very limited [1].

The pure condensing unit can solve the problem of survival by heating transformation. Under the current power situation, it is necessary to implement thermal electro-coupling by providing a peak-regulating heat storage device, and finally realize the flexibility of the unit. According to statistics, there are more than 160 200MW three-cylinder three-row steam condensing steam turbine generator sets in China, and some of which have been transformed by heat supply. However, it is necessary to carry out new technical transformation to further improve the heating capacity of the unit and reduce the coal consumption index of the unit [2].

Long-ying Z et al. [3] established a peaking performance prediction model for 300MW heating units, and analysed the main factors affecting the peaking performance and the peak range of the unit. Kai W et al. [4] pointed out the important role of thermal storage technology in expanding the peaking margin of the unit. Quan L[5] and others analysed the electro thermal characteristics, operating mechanism and peaking capacity of the thermoelectric unit after heat storage. The above-mentioned literatures only carry out model construction from the perspective of peak-regulating heat storage or condensation back-heating units, peaking ability and technical economic analysis, and fail to analyse the unit flexibility operation from the perspective of the system.
Based on the above research, this paper studies and analyses the peak-shaving application and economic analysis of the coupling of optical axis heating and heat storage technology for 200MW pure condensing unit.

2. Retrofit technology for thermal power flexibility

In the winter heating period, the co-generation unit is “heat-set”, which is easily restricted. The "thermal power contradiction" phenomenon has greatly limited the peak shaving capacity of the unit. Under normal circumstances, the load fluctuation of the grid and the heating network is just opposite in a period. For example, during the daytime, it is often the peak period of electricity consumption, but it is the period of hot valley; the opposite is true at night. As shown in figure 1.

2.1. Optical axis heating technology

The optical axis heating technology is to remove all the through-flow of the double-split in the low-pressure cylinder of the steam turbine unit, replace it with an optical axis, and increase the connecting pipe to transform the pure condensing unit into a heating unit. For the three-cylinder three-exhaust steam unit, a part of the steam discharged from the medium-pressure cylinder is still working in the #1 low-pressure cylinder (low-pressure cylinder connected to the intermediate-pressure cylinder), and the steam no longer enters the #2 low-pressure cylinder (symmetrically arranged low-pressure cylinder).

2.2. Thermal storage technology

Heat storage technology is still in its infancy in China. Under the premise of normal operation of the unit, when the heat load is low during the day, the excess steam extraction heat of the unit is stored in the heat storage tank, and the heat releases at night. The heat storage system designs according to the layering principle of hot water. When the heat is stored, the hot water enters from the upper water pipe, cold water discharges from the lower water pipe, and the transition layer moves downward. When the heat release, the hot water discharges from the upper water pipe, the cold water enters from the lower water pipe, and the transition layer moves up.

In this paper, combined with the characteristics of heat load, the daytime heat storage time is set to 17 hours, and the night-time heat release time is set to 7 hours.

3. Thermodynamic model analysis

3.1. Electro thermal characteristics of units

The coupling relationship between the power generation power $P$ and the external heating power $h$ calls "electrical heating characteristics". Under a given thermal load, the power generation has a certain degree of adjustability. The greater the heating power, the smaller the range of power generation adjustable. This is because, given a steam extraction, the unit can adjust the output power of the entire turbine by adjusting the main steam quantity, but the larger the steam extraction, the smaller the proportion of main steam that can be used for adjustment\(^5\).
3.2. Electro thermal characteristics of units with heat storage

The electro thermal characteristics of the unit will change after the addition of the heat storage system. For a certain power generation, the overall maximum heating power of the unit will increase to a certain level based on the original after the heat release process of the heat storage tank, which is the maximum heat release power of the heat storage tank designed. In general, after the addition of the heat storage system, the power generation range of the unit adjusts wider than before, and the part of the unit that is insufficiently heated can be compensated for heat supply or heat storage by the heat storage tank.

4. Thermodynamic analysis

4.1. Basic situation

The example in this paper is two sets of 200MW three-cylinder three-row steam pure condensing unit in a power plant in Northeast China. In order to meet the demand of 250×10^4m^2 heating for power load deep peak shaving and heat user side, it is proposed to select the unit connecting pipe for extraction and optical axis extraction. A heating technology retrofit solution coupled with thermal storage technology. Figure 2 is a system diagram of optical axis heating combined with thermal storage tank. An optical-axis rotor replaces the rotor of the low-pressure cylinder of the steam turbine, and the steam is extracted from the opening of the steam-conducting pipe for heating. The system is equipped with a normal-pressure heat storage tank directly connected to the heating network system.

![Figure 2. System diagram of optical axis heating combined with thermal storage](image)

After the implementation of different technologies for the 200MW three-cylinder three-row steam pure condensing unit of the power plant, the main technical parameters are shown in Table 1.

| Items                      | New Steam Flow Generation | Connecting Pipe Extraction | Optical Axis Extraction |
|----------------------------|---------------------------|---------------------------|-------------------------|
| Steam Flow Generation      | MW                        | 610                       | 610                     |
| Heating Steam Extraction   | t/h                       | 670                       | 610                     |
| Heating Exraction          |                           | 610                       | 610                     |
| Heating Exraction          |                           | 320                       | 370                     |
| Heating Exraction          |                           | 193.36                    | 196.08                  |
| Heating Exraction          |                           | 200.71                    | 163.67                  |
| Heating Exraction          |                           | 90.45                     | 102.58                  |
| Heating Exraction          |                           | 5774.21                   | 7659.01                 |

4.2. Result analysis

4.2.1 Comparison and selection of peaking technology schemes. The technical analysis of coupling heating with heat storage technology and comparison and selection of different operation modes, the
technical transformation of the unit connected pipe extraction and optical shaft heating for 200MW condensing unit are carried out respectively.

4.2.1.1 Connected pipe extraction heating with different new steam capacity. Figure 3 and figure 4 are the change curves of generating power and heating available area of the unit under the condition of different new steam capacity when the unit heating extraction capacity changes between 10t/h and 120t/h. The maximum heating extraction capacity is 120t/h; the heating comprehensive heat index is 57.2 W/m². The electric power of the unit decreases with the increase of the amount of steam extraction heating, and the two are inversely proportional. The lower the new steam capacity of the unit, the lower the generating power. As the extracted steam is medium grade superheated steam, and more extraction will make the steam turbine do less work, thus reducing the generating power of the unit. The heating area of the unit is directly proportional to the extraction capacity, and it is not affected by the new capacity. The reason is that the area available for heating is related to the extraction volume and extraction parameters, and the extraction parameters are stable.

![Figure 3. Influence of Heating Steam Extraction on Power Generation under Different New Steam Volumes](image)

![Figure 4. Influence of Heating Steam Extraction on Heating Area under Different New Steam Volumes](image)

4.2.1.2 Optical shaft heating with different new steam capacity. Figure 5 and figure 6 are the change curves of generating power and heating available area of the unit under the condition of different new steam capacity when the unit heating extraction capacity changes between 10t/h and 120t/h. It is known that the electric power of the unit decreases with the increase of the amount of steam extraction heating, and the two are inversely proportional. The lower the new steam capacity of the unit is, the lower the generating power will be. As the extracted steam is medium grade superheated steam, and more extraction will make the steam turbine do less work, thus reducing the generating power of the unit. At the same time, in the case of the same new steam capacity, the optical shaft transformation makes the steam extraction capacity of the unit greatly increase, and the flexibility of power load and heat load regulation is enhanced. The heating area of the unit is directly proportional to the extraction capacity, and it is not affected by the new capacity. It is because that the area available for heating is related to the extraction volume and extraction parameters, and the extraction parameters are basically stable.

4.2.1.3 Comparative analysis of peak operation schemes of coupled heat storage technology. The comparison and selection of peak load regulation schemes for coupled heat storage technology is mainly combined with heat storage devices to achieve flexible and deep peak regulation of thermal power (generating load of unit <104MW) and strive for a high peak load regulation subsidy price as much as possible. It must also meet the precondition of 250×10⁴m² residential heating area. Table 2 is obtained through calculation and analysis, which is a comparative analysis table of different heating transformation schemes.
In scheme 1, the connecting pipes are extracted during the day and night. In order to meet the heating and heating requirements, the power of the heating unit needs to be kept at a high level, and power peaking cannot be performed. In scheme 2, optical axis heating is conducted in day and night, which can be used for power depth peaking regulation. However, the amount of steam extraction is large after the transformation of optical axis heating, and the heating load is much larger than the external heat load demand. In scheme 3, scheme 4 and scheme 5, an optical axis and a connected pipe for steam extraction and heating conducts in day and night, which can achieve the power depth peaking regulation. However, the power load reduction of scheme 3 is limited, and the heating load of scheme 4 is far more than the external heat load demand. Through comprehensive comparison, it can be concluded that the power load of scheme 5 can be reduced to a lower level, which can more fully meet the demand of power flexibility, deep peak regulation and heat storage.

In scheme 5, one unit transforms into an optical shaft-heating unit. During the day, the heating steam extraction capacity is 253t/h, which can meet the external heating demand. At the same time, the heat storage tank can store 819.49GJ of heat. At night, the unit maintains the minimum intake...
capacity of steam turbine pumping 155 t/h, and the electrical load is 88MW (the load rate is 44%). The heat stored during the day can meet the heating gap of the unit at night. Therefore, the external heating demand can be met by the heat storage system at night. The other unit can consider communicating pipe extraction steam heating operation mode, and electrical load peak shaving.

4.2.2 Economic benefit analysis. The economic benefits of the peak-regulating heat storage system refer to the policy subsidies given by the government minus the operating costs of the system. According to the compensation mechanism corresponding to different peaking depths, the specific compensation amount calculates as follows:

$$\text{Peak adjustment compensation amount of thermal power plant} = \sum_{i=1}^{3} (\text{paid peak charge in grade } i \times \text{clearing price in grade } i)$$

Among them, paid peak charge defines as the non-generated power of thermal power plants in the paid peak load regulation range.

Figure 7 shows the daily peak load distribution time of the power plant during the heating period of 2014-2015. The cumulative peaking time is 884 hours, and the average peaking time is between 3.5 hours and 5.8 hours.

Figure 7. Temperature distribution peak time distribution during heating period

The main income of power plant peaking is the government's peaking price subsidy. According to the "Northeast Electric Power Auxiliary Service Market Operation Rules": When the peak load rate of the first stage of thermal power unit is between 40% and 50%, the maximum subsidy for electricity price is 0.4 yuan/kWh. When the second-stage peak load ratio is less than or equal to 40%, the maximum subsidy for electricity price is 1.0 yuan/kWh. The government subsidies obtained by the project is shown in table 3.

According to the investment analysis, the total investment cost of the project technical transformation is 18 million yuan. The internal rate of return on project capital is 44.56%, the net profit rate of capital is 48.85% and the payback period of project investment is 5.6 years. The project investment is small and the economic benefit is high.

| years       | unit       | Annual income |
|-------------|------------|---------------|
| 2018        | Million yuan | 3.22           |
| 2019        | Million yuan | 3.56           |
| 2020        | Million yuan | 3.90           |
| 2021        | Million yuan | 4.24           |
| 2022 and beyond | Million yuan | 4.24           |

5. Conclusion
Based on two 200MW three-cylinder and three-exhaust steam pure condensing units, under the condition of satisfying power load depth peaking regulation and the demand of 250×10^4m² thermal
After the implementation of the connecting pipe extraction and the optical axis heating reform, the power generation of the unit decreases with the increase of the steam supply heat under different new steam conditions, and the two are inversely related. The lower the new steam volume is, the lower the power generation capacity of the unit will be. The heating area of the unit is directly proportional to the extraction capacity.

The coupling of the optical shaft heating and the heat storage technology can not only give full play to the heating capacity of the unit, but also realize the ‘thermoelectric decoupling’ and improve the flexibility of thermal power. Under certain external heat load demand, the power generation load can be reduced to 88MW when optical axis heating (only 44% of rated load).

Under the condition of satisfying certain external heat load demand, there is an optimal combination of peak shaving schemes among different coupling heating modes, that is, scheme 5. This peak-regulation scheme can fully realize the deep peak-regulation of power units, so as to obtain a higher peak-regulation subsidy price and maximize economic benefits. According to the economic analysis, the internal rate of return of project capital is 44.56%, the net profit rate of capital is 48.85%, and the payback period of project investment is 5.6 years, with high economic benefit. It is suggested to popularize and apply the peak-regulation subsidy policy in the northern heating areas where wind and light are seriously abandoned.

References
[1] Zheyi P, Xinlei W and Cun D 2017 Analysis of Impact of CHP Plant on Renewable Energy Accommodation in Northeast China and Thermoelectric Decoupling Measures J. Power System Technology 41(6) 1786-92 (in Chinese)
[2] Feng S, Pengda Z and Rui T 2017 Research on Heat Supply Retrofit of Triple-cylinder Triple-exhaust Condensing Steam Turbine of 200 MW Units J. Zhejiang Electric Power 36(3) 51-54 (in Chinese)
[3] Long-ying Z, Xue-lei Z and Shu-feng Y 2016 Investigation of Peak Regulation Capability and Influence Factors in a 300MW Cogeneration Power Plant J. Turbine Technology 58(5) 391-5 (in Chinese)
[4] Kai W, Hao-ming T and Jing J 2012 Expanding the Peak Regulation Margin of Heating Units by Using Heat Storage Technology J. Energy Conservation Technology 30(174) 339-41 (in Chinese)
[5] Quan L, Tianyou C and Haixia W 2014 Analysis on Peak-load Regulation Ability of Cogeneration Unit with Heat Accumulator J. Automation of Electric Power Systems 38(11) 34-41 (in Chinese)