Research and application of thermal power unit’s load dynamic adjustment based on extraction steam

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Abstract. The rapid development of heat and power generation in large power plant has caused tremendous constraints on the load adjustment of power grids and power plants. By introducing the thermodynamic system of thermal power unit, the relationship between thermal power extraction steam and unit’s load has analyzed and calculated. The practical application results show that power capability of the unit affected by extraction and it is not conducive to adjust the grid frequency. By monitoring the load adjustment capacity of thermal power units, especially the combined heat and power generating units, the upper and lower limits of the unit load can be dynamically adjusted by the operator on the grid side. The grid regulation and control departments can effectively control the load adjustable intervals of the operating units and provide reliable for the cooperative action of the power grid and power plants, to ensure the safety and stability of the power grid.

1. Introduction

Cogeneration refers to the power plant that is producing electricity, and with steam turbine generator which have done work for user heating mode of production, namely the technological process of the production of electricity and heat at the same time, compared to save fuel production of electricity, heat, respectively. The cogeneration of heat and power can save energy, it also can improve the environment condition by reducing small boilers.

Cogeneration is changed in a large power plant which will be the future trend of the development of large coal power stations, large power stations of cogeneration in keeping the steam and power generation, on the basis of high efficiency and large capacity, can provide meet the requirements of industrial boiler load, replace the industrial boiler, and can keep the heat supply efficiency. Heat and electricity generation has the comprehensive benefit of saving energy, improving the environment, improving the quality of heating and increasing the power[1,2]. Utilizing cogeneration district heating technology to replace the scattered heating network composed of small inefficient coal-fired boiler rooms.

At present, power structure of China's northern heating area depend on thermal power and mostly for the combined heat and power generating units, during the winter, resulting in insufficient power grid peak regulation capacity. Survey data show that the actual load demand of the northeast power grid winter is 13.40GW, and thermal power installed 76.93GW, 78% of the electricity generating, provide maximum load capacity of 7.70GW, can meet the demand of the northeast power grid during
the winter peak regulation of only 57%. How to effectively monitor the thermal power unit, especially the cogeneration unit load adjustment capacity, and to effectively control the power grid regulation and control is the focus of attention[3].

2. Load Control Range and Thermodynamic Model

2.1. Control Range

In the energy management system (EMS) of power grid, the normal load control range of the thermal power unit is shown in figure 1. In the power plant controller (PLC), the rated power Pe of the unit is set on the regulating upper Ad.H port, and 50%Pe of the unit is set to adjust the lower level Ad.L port. Due to the control of systems without considering the unit heating exhaust steam for the unit as a part of the total steam flow, heating exhaust steam inevitably cause the shortage of the load flow, on the one hand to make the unit in high load cannot ascend load due to insufficient power of steam flow unit power, on the other hand, low load does not guarantee the safe and stable operation of generating unit, ultimately resulting in a decline in the load peak regulation performance of the power grid, the grid frequency fluctuation influence the safety of the whole society.

![Figure 1. Schematic diagram of load control range of the thermal power unit](image)

For thermal power units, there is the maximum power generation and minimum power generation. Among them, the power plant boiler performance assessment, the unit maximum output as the boiler maximum continuous rating (BMCR) conditions, and manufacturers supply technical agreement is usually provided on the boiler does not allow more than BMCR operating conditions. This is because the overload operation, the flue gas radiation heat is likely to cause the heating surface burst pipe, and the amount of flue gas and fly ash fly ash flow rate is likely to cause damage to the heating surface, reducing boiler operation reliability and safety[4,5]. Therefore, the maximum allowable steam volume corresponding to the maximum generating power of the steam turbine should be consistent with the main steam flow rate of the BMCR. The minimum steady combustion power of the unit, that is, the minimum load that the boiler does not use for auxiliary fuel combustion and which is capable of long-term, continuous and stable operation is usually 50% of the rated power of the unit. The maximum power generation power decreases with the increase of the pumping volume, and the minimum steady combustion power increases with the increase of the steam volume.

2.2. Thermodynamic Model

2.2.1. Coefficient calculation method

At the beginning and end of the steam turbine, when the final parameters are the same, there is a specific relationship between the power generation, the amount of steam extraction and the steam intake of the combined heat and power unit. According to the first design principles, the heating cogeneration unit is designed, assumptions, the value of extraction pressure, main steam pressure, back pressure are constant value. The affects of the quantity of admission with each cylinder back pressure change can be neglected, so that each cylinder inlet steam flow can be completely controlled by the valves. If the steam flow with the change of the opening of regulator is linear that the
corresponding unit’s power of each cylinder also along with the change rate of flow is linear[6].

Meanwhile, assume that the time constant of the high, medium and low oil motivations are same.

According to the condition that the unit reaches the max and min power and the relationship
between the efficiency and the flow rate of the regulating unit of the fitted unit and the calculation
result of the reference working condition. According to each valve of flow curve, D10, D20 and D30
can be obtained by various valve opening and flow rate, the relationship between maximum of the
opening of steam flow. According to thermodynamic calculations control and operating mode chart,
get the corresponding flow valve of each cylinder power. According to the above calculated the
amount of each cylinder of steam and power, coupling coefficient can be obtained directly. Using the
above obtained coupling coefficient, decoupling coefficient can be calculated.

2.2.2. Fundamental relations

According to assumptions, single pumping unit is equivalent to a back-pressure machine and a pure
condensate coaxial machine. The schematic diagram of single exhaust steam turbine is show in figure
2.

\[
\begin{align*}
\text{Figure 2. Single exhaust steam turbine schematic diagram} \\
\text{Accompanying single exhaust steam turbine regulating system diagram is shown in figure 3.}
\end{align*}
\]

\[
\begin{align*}
\text{Figure 3. Single exhaust steam turbine regulating system diagram} \\
\text{Power and extraction quantity relation as follows} \\
\begin{cases}
N = N_1 + N_2 \\
D_{ex} = \alpha(D_1 - D_2)
\end{cases}
\end{align*}
\]

\[\alpha\] is the coefficient is less than 1, to consider the influence of the amount of heat extraction on
extraction.
\[ \alpha = \frac{D_{ex0}}{(D_1 - D_2)_0} \]

Linear power, flow regulating valve opening characteristic

\[ \begin{align*}
N_1 &\propto D_1 \propto m_1 \\
N_2 &\propto D_2 \propto m_2
\end{align*} \]

By the high pressure adjusting value control unit's acceleration, interconnection, load, until with full load. The host extraction point should have been higher than the rated pressure extraction steam pressure, meet with heat load conditions.

3. Optimization Control System Design

Based on the working principle of the thermoelectric unit, the maximum power generation with the increase in the amount of steam continued to decrease, the minimum steady combustion power increases with the increase in exhaust steam. One dynamic adjustment system for the load capacity of thermal power units based on exhaust steam flow is designed, it include signal collector, analog generator, subtracter, multiplier, function generator, adder, analog switcher, manual input and power plant controller. The signal collector after function generator conversion, one way to the subtracter with analog generator for difference, one way to the adder with 50% analog generator for sum, and the value of the difference and sum respectively after analog switcher to the power controller.

![Figure 4. Schematic diagram of dynamic adjustment system for the load capacity of thermal power units based on exhaust steam flow](image)

Taking the conventional 300MW subcritical unit as an example, the boiler is a single furnace with a balanced ventilation, an intermediate reheat, natural circulation drum boiler, maximum continuous evaporation capacity of 1025t/h, and maximum steam flow of 200 t/h in winter heating. Some comparison data of extraction unit is shown in table 1.

| Working condition | No Extraction steam | Extraction steam |
|-------------------|---------------------|------------------|
| Unit load         | Total steam flow    | Extraction steam |
| Unit load         | Total steam flow    | Extraction steam |

**Table 1. Extraction steam and unit load comparison data**
First, the conversion coefficient between the steam flow and the load is calculated. Since 300MW corresponds to 1025t/h, the corresponding power of 200t/h is \[ \frac{300}{1025} \times 200 = 58.54 \text{ MW} \]. Therefore, the function \( f(x) \) expression can be set to

| Heat extraction flow (t/h) | Power conversion (MW) |
|---------------------------|-----------------------|
| 0                         | 0                     |
| 200                       | 58.54                 |

When the unit is not exhausted, the output of the manual input device D/MA is the switch 0. The setting side of analog switcher AXSEL1 and the analog switcher AXSEL2 is the switch 0, and the output is the input value of Z2, that is, when the power plant controller PLC adjustment upper limit Ad.H value of 300MW, adjust the lower limit Ad.L value of 150MW.

When the unit is exhausted, the operator set the switch 1 by the manual input device D/MA. The setting side of analog switcher AXSEL1 and the analog switcher AXSEL2 is the switch 1, and the output is the input value of Z1. If this time, the signal collector S collected by the extraction flow rate of 100 t/h, the function generator \( f(x) \) conversion output conversion power 29.27 t/h.

It is calculated that the output of the DEV is MW, that is, the maximum power value that the unit can do after deducting the exhaust flow. This value is the Ad.H of the PLC of the power plant controller. The output of the ADD is MW, it is that the minimum steady-state power is supercharged with the flow rate converted by the flow rate, which is the Ad.L of the power plant controller PLC.

4. Conclusion

The harmonic performance of the connected-grid unit directly affects the stability of the whole region grid frequency. By optimizing the design of adjustment range, it can dynamically adjust the upper and lower limits of the unit to ensure that the unit is within the controllable range and ensure that the inverter does not undergo the ineffective adjustment. Frequency stability, and thus ensure that the safe and effective operation of majority of users’ equipment. Results show that the proposed algorithm can satisfy control effects even for large load varying ranges. On the one hand can solve the problem that the thermal unit in the high load due to the lack of load steam flow caused by the unit power cannot improve, on the other hand to ensure that the unit at low load safe and stable operation. Technical achievements provide the basis for further enhancing the peaking capacity of existing cogeneration units and promoting wind power consumption.

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