

Economic analysis of thermal power units operating under unconventional conditions

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Abstract. In the case of deep peak shaving of thermal power units, it can absorb more photovoltaics and wind power, and also reduce the efficiency of thermal power plants and increase the environmental cost of society. This paper analyses the thermal power units under unconventional conditions from several influencing factors. The economics of operation, and innovative consideration of the current on-grid price and the latest government peaking subsidy factor. Firstly, according to the operating state and energy consumption characteristics of thermal power units, the peaking process is divided into conventional peaking, no oil depth adjustment and oil injection depth peaking, and the main factors affecting the deep peaking capacity of thermal power plants are analysed. The peaking energy cost model of thermal power units at different stages, and the actual power plant as the research object, the simulation results under different scheduling strategies are given. The results show that it is the most economical to increase the peaking depth of the unit to 54% of the rated capacity. The research results will provide a reference for better consumption of new energy.

1. Introduction

At present, China's thermal power units have basically reached saturation, and the unit capacity ratio is high. The rapid adjustment of power supply capacity is far from meeting the peaking demand. In the case of more and more serious abandonment, social, power grid and wind power enterprises require thermal power plant depth. The voice of peaking is getting higher and higher. Because wind power output has the characteristics of intermittent, random, anti-peaking, etc., large-scale wind power integration increases the peak-to-valley difference of system load. Under the condition that the existing peaking resources are insufficient, the system peaking pressure is getting larger and larger. This has become the main reason for the large-scale abandonment of wind power in the domestic power grid, and is the main contradiction affecting the healthy development of China's new energy. Wind power utilization has a declining trend. In the context of the increasingly severe wind curtailment, social and wind power companies are demanding more and more high-level peaking of thermal power units.

In the power system, there is a problem that the capacity of the thermal power unit is too large, the power supply structure is unreasonable, and the water and power peaking resources are insufficient



and fast. Therefore, the peaking task added by the large-scale wind power after grid connection is mainly undertaken by the thermal power unit. According to the conventional peaking requirements, thermal power units are often unable to suppress large-scale fluctuations in large-scale wind power, especially when wind power has obvious anti-peak characteristics, which will cause a large amount of wind. In order to make full use of wind power, the current system dispatching will require some thermal power units with regulation capability to operate below the minimum technical output (usually 45% to 50% of rated power). At this time, the thermal power unit works in the deep peaking stage. The operating cost efficiency of thermal power units in the deep peaking stage is greatly reduced, and its operating costs include not only explicit costs such as fuel, but also hidden costs such as risk and wear life loss. However, from the current operating situation, for one thing, the willingness to deep peak peaking of thermal power plants is insufficient; for another, the deep peaking of thermal power units will greatly increase system energy consumption and pollutant emissions, which is not conducive to the improvement of energy efficiency of power systems. Therefore, we must study the economics of deep peak shaving of thermal power units from large-scale wind power grid-connected conditions from thermal power enterprises, wind power enterprises and society.

Under the conditions of large-scale wind power grid-connected, the economic analysis of the thermal power system participating in the system after the deep peak shaving is more complicated. Evaluations from the perspective of grids and power plants are often lacking from a social perspective and considering environmental and social benefits. Based on the operating state and energy consumption characteristics of thermal power units, this paper analyzes the main influencing factors of deep peak shaving in thermal power plants from a technical point of view, and then proposes a peaking energy cost model for different stages of thermal power plants that takes into account unit life loss and environmental benefits. Taking an actual power plant as an example, the simulation results under different scheduling strategies are given. The results show that it is most economical to increase the peak shaving depth of the unit to 54% of the rated capacity. The research results will provide a reference for better consumption of new energy.

2. Analysis of peaking process of coal-fired power unit

For the general thermal power unit, the peaking can be divided into three stages: conventional peaking, no oiling depth peaking, and oiling depth peaking. In recent years, with the continuous reduction of the average utilization hours of wind power, the problem of wind curtailment has become more and more serious, and the voice of the society to explore the ability of deep thermal peaking of thermal power units is getting higher and higher. The grid company has significantly increased the peaking depth of the peaking unit within the peak range allowed by the thermal power plant.

The deep peaking ability of thermal power units is affected by many factors, including boiler combustion stability, hydrodynamic working condition safety, boiler auxiliary equipment parameters and operating personnel level.

Boiler combustion stability is the key influencing factor for limiting the peaking capacity of thermal power units. The stability of boiler combustion process will be affected by the stress of boiler metal materials, coal quality characteristics, fineness of coal powder concentration, hot air temperature, hot air speed and so on. The influence of various factors. The safety of hydrodynamic conditions cannot be ignored when the boiler is running at low load. During the rapid load change of the boiler, the thermal deviation of each circulating pipeline of the water wall is too large, resulting in a decrease in the water circulation flow rate, and the water circulation is stagnant or reversed. Boiler auxiliary equipment is an auxiliary equipment necessary for boiler combustion such as milling system, water pump and fan. When the boiler is running at low load, due to large inertia and difficult to adjust quickly, the milling system is prone to coal plugging or coal breaking during operation, which has a great impact on the stable combustion of the boiler, and the probability of failure of the pump and the fan is greatly increased.

During the low-load operation of the boiler, the monitoring and protection and control systems may frequently generate alarms and actions due to the critically stable operation of the boiler body and

auxiliary equipment. Relevant operational personnel need to be highly focused, control and handle alarm signals in a timely and agile manner, complete the stable combustion and combustion support of the boiler, to prevent the occurrence of adverse boiler explosion accidents, causing major economic losses and casualties. Therefore, the participation of thermal power companies in deep peaking will not only greatly increase operating costs, but also bear the risk of boiler accidents, so it is impossible to have the initiative to peak peaking.

In recent years, with the continuous improvement of the design and manufacturing technology of the unit, the newly-introduced thermal power units such as supercritical units and ultra-supercritical units adopt new technical means and high-quality steel with high temperature corrosion resistance, and the temperature difference thermal stress of the unit is effective under variable working conditions. The reduction is more important than the previous thermal power units in terms of combustion stability and safety of hydrodynamic conditions.

3. Analysis of peaking cost of coal-fired power unit

In the conventional stage, the peak energy consumption cost of the thermal power unit is composed of the coal consumption cost, which is usually calculated by the consumption characteristics. Therefore, the coal consumption cost of thermal power units is:

$$f(P) = (aP^2 + bP + c)Z_c \quad (1)$$

where P is the output of the thermal power unit; a , b , and c are the coefficients of the unit's consumption characteristic function, and the values are related to the unit type, boiler type and coal quality, which can be obtained through online calculation. Z_c is the coal price for the quarter, yuan / t.

In the stage of peaking of oil injection and peaking of no oil injection, the low pressure output makes the thermal stress of the rotor shaft of the unit too large, and the excessive alternating thermal stress will cause low cycle fatigue loss and creep loss. Lead to serious deformation and breakage of the unit body, reducing the life of the unit. At present, there is still no effective monitoring and protection method for the excessive thermal stress of steam turbine rotors, and it is difficult to determine the impact on rotor life. Since the calculation of the rotor life of a steam turbine is a very complicated problem, there is no recognized calculation formula that can be effectively solved in the current research. In this paper, the low cycle fatigue life loss calculation is performed according to the low cycle fatigue characteristic relationship of the rotor material, so the variable load is adjusted. The cost of loss under the peak unit is:

$$w_s(P) = \lambda Z_j / (2V_f(P)) \quad (2)$$

where λ is the operating coefficient of the thermal power unit, indicating the degree of influence of different operating conditions on the unit loss, $V_f(P)$ is the rotor cracking cycle, it can be determined by the rotor low cycle fatigue curve; Z_j is the unit purchase cost.

During the peaking stage of oil injection, the combustion stability of the boiler and the safety of hydrodynamic working conditions are rapidly declining, and there is a situation in which stable combustion cannot be achieved. The unit needs to be fuelled to ensure safe operation of the unit. The fuel consumption cost is:

$$W_o = C_c Z_o \quad (3)$$

where C_c is the fuel consumption of the unit when it is fuelled; Z_o is the oil price of the season, yuan / t.

At the same time, the thermal power unit will reduce the desulfurization efficiency and increase the sulphur content in the pollutant emissions. The fuel consumption of the unit will increase the emission of pollutants such as nitrogen oxides and soot, resulting in an increase in the sewage charges of the thermal power plant. Excessive emissions of pollutants will violate government standards for emission of air pollutants from thermal power plants and result in government fines. Therefore, the environmental additional cost is:

$$w_h(P) = 1600f(P)\mu_s\Delta\theta + o_c W_f + S_p(P, o_c) \quad (4)$$

where $\Delta\theta$ is the change value of desulfurization efficiency; μ_s is the total sulphur content of coal combustion; o_e is the fuel consumption when the unit is put into operation and stable combustion; W_f is the exhaust gas discharge fee generated by unit fuel; S_p is when the pollutant discharge exceeds the standard. The penalty function, n , is related to the extent to which pollutant emissions exceed the standard.

Therefore, the energy cost of the thermal power unit during the peak shaving process can be expressed in stages. In the conventional peak shaving stage, the peak energy consumption cost of the thermal power unit is composed of the running coal consumption cost; in the stage of no oil injection depth peaking, the safety of the unit operation Reduced, the peak energy consumption cost of the thermal power unit is composed of the coal consumption cost and the unit loss cost; in the peak stage of oil injection, the boiler needs to be fuelled to support combustion, and the energy consumption cost of the thermal power unit is controlled by the coal consumption cost and the unit loss. Cost, fuel consumption, and environmental additional costs. That is, the peak energy consumption cost of the thermal power unit is:

$$C(P) = \begin{cases} f(P), & P_{\min} < P \leq P_{\max} \\ f(P) + w_s(P), & P_a < P \leq P_{\min} \\ f(P) + w_s(P) + W_o + w_h(P), & P_b < P \leq P_a \end{cases} \quad (5)$$

where P_{\max} to P_{\min} is the basic peaking of the thermal power unit, P_a to P_{\min} is the peak regulation of the thermal power unit without oil injection, and P_b to P_a is the peaking of the oil injection depth of the thermal power unit.

For the current government peaking subsidy policy, if the power plant unit is in a state of deep peak shaving, the peaking depth at different stages is in accordance with national policies, and the government will generate electricity for the unit due to the stable power generation of the unit due to stable grid frequency. The cost is increased and the corresponding compensation is made.

Assume that when the unit load is lower than $u_1\%$, the unit is in the state of deep peak shaving, and the peaking subsidy price is N_1 ; assuming that when the unit load is lower than $u_2\%$, the unit is in a deeper level peaking state, in this state, the unit The efficiency of desulfurization and denitrification has dropped drastically, increasing the cost of environmental protection; during this peaking phase, the peak subsidy price is N_2 . Then the peak subsidy benefit W_b is:

$$W_b = \begin{cases} (u_1\% P_N - P_i) N_1 & u_2\% P_N \leq P_i \leq u_1\% P_N \\ (u_1\% - u_2\%) P_N N_1 + (u_2\% P_N - P_i) N_2 & P_{i,\min} \leq P_i \leq u_2\% P_N \end{cases} \quad (6)$$

Under the premise of meeting the national mandatory standards for pollutant discharge, the optimal distribution of the overall economic benefits of the whole plant is used as the optimization target. The comprehensive economic benefit is the electricity sales revenue and coal consumption cost and sewage discharge considering the dust removal, desulfurization and denitrification compensation electricity price. The difference in fees. Assuming that the plant's power consumption rate is $n\%$ and there are a total of m units, the on-grid power in time T is:

$$E(P_i) = (1000 - n)T \sum_{i=1}^m P_i \quad (7)$$

where $E(P_i)$ is the total factory power consumption in time T .

If the electricity price is p_1 yuan /KW*h, the electricity sales revenue in time T is:

$$W(P_i) = E(P_i) \times p_1 \quad (8)$$

4. Grid economic dispatch model and energy efficiency model

Under the premise of meeting the constraints of load and system operation, all thermal power units participate in basic peak shaving, consider the deep peak shaving capacity of some units, and reasonably distribute the output of thermal power units. The grid economic dispatching model for large-scale wind power integration is usually based on system operating cost. (Coal cost and start-stop cost) is the minimum target, and the economic dispatch objective function is expressed as:

$$\min \sum_{t=1}^T \sum_{i=1}^M K_{i,t} \left[f_i(P_{i,t}) + K_{i,t}(1-K_{i,t-1})C_u + K_{i,t-1}(1-K_{i,t})C_d \right] + \omega \sum_{t=1}^T (P_{w,t}^{pr} - P_{w,t}) \quad (9)$$

where T is the number of scheduling periods; M is the number of units; $K_{i,t}$ is the state variable of unit i running at time t, $K_{i,t} = 0$ is the stop state, $K_{i,t} = 1$ is the running state, $P_{i,t}$ is the output of unit i at time period t, $f_i(P_{i,t})$ is the coal consumption cost of unit i running during t period, C_u and C_d are the starting cost and the stopping cost of unit i respectively. ω is the discarding coefficient of abandonment, $P_{w,t}^{pr}$ is the predicted output value of wind power in period t, and $P_{w,t}$ is the actual output value of wind power in period t.

Power balance constraint:

$$\sum_{i=1}^N U_{i,t} P_{i,t} + P_{w,t} = P_t + P_c \quad (10)$$

Unit power constraints. For conventional peaking units:

$$U_{i,t} P_{i\min} \leq P_{i,t} \leq U_{i,t} P_{i\max} \quad (11)$$

For deep peaking unit:

$$P_{i\min} \leq P_{i,t} \leq P_{i\max} \quad (12)$$

Minimum start and stop time constraint:

$$\begin{cases} (U_{i,t-1} - U_{i,t})(T_{i,t-1}^{\text{on}} - T_{i\text{on}}) \geq 0 \\ (U_{i,t} - U_{i,t-1})(T_{i,t-1}^{\text{off}} - T_{i\text{off}}) \geq 0 \end{cases} \quad (13)$$

Unit climbing rate constraint:

$$U_{i,t-1} P_{i,t-1} - \alpha_{i\text{down}} \leq P_{i,t} \leq \alpha_{i\text{up}} + U_{i,t-1} P_{i,t-1} \quad (14)$$

Wind power grid power constraints:

$$0 \leq P_{w,t} \leq P_{w,t}^* \quad (15)$$

Contact line power constraint:

$$-P_{\text{cmax}} \leq P_c \leq P_{\text{cmax}} \quad (16)$$

where P_t is the electrical load; P_c is the tie line power; $P_{i\max}$ and $P_{i\min}$ are the minimum technical output and maximum technical output of the thermal power unit i; $\alpha_{i\text{up}}$ is the upward climbing rate of the unit i; $\alpha_{i\text{down}}$ is the downward climbing of the unit i Rate; $T_{i\text{on}}$ is the minimum continuous running time of unit i; $T_{i\text{off}}$ is the minimum continuous stopping time of unit i; $T_{i,t-1}^{\text{on}}$ is the time for unit i to continuously run at time t; $T_{i,t-1}^{\text{off}}$ is the time for unit i to stop continuously at time t, $P_{w,t}$ is the output of wind power, $P_{w,t}^*$ is the wind power predicted values, P_{cmax} is the maximum delivered power of the tie line.

5. Multi-angle economic analysis of scheduling scheme based on example

In this paper, the standard 10-machine system is used for simulation. In the example, the capacity of the thermal motor assembly machine is 1600MW, the installed capacity of wind power is 900MW, the setting P_a is 60% of P_n , P_b is 45% of P_n , and P_c is 30% of P_n .

The economic dispatching of the power grid is from the perspective of the power grid, with the goal of minimizing the operating cost of the system. It does not take into account other costs of increasing the peak peaking of the thermal power unit. Through simulation analysis, with the increase of the peaking depth, the unit's loss cost and oil investment. The cost continues to increase, but the number of start-stops is significantly reduced, and the cost of start-stop is also reduced. After the peak-shaving depth of the thermal power unit is increased, the deep-tuning unit is in a deep-adjusted state for a long time, and the adjustment effect is very obvious.

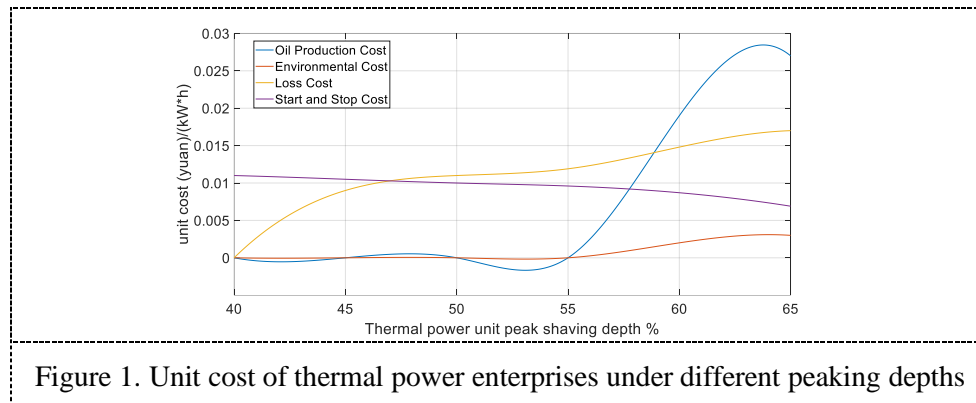
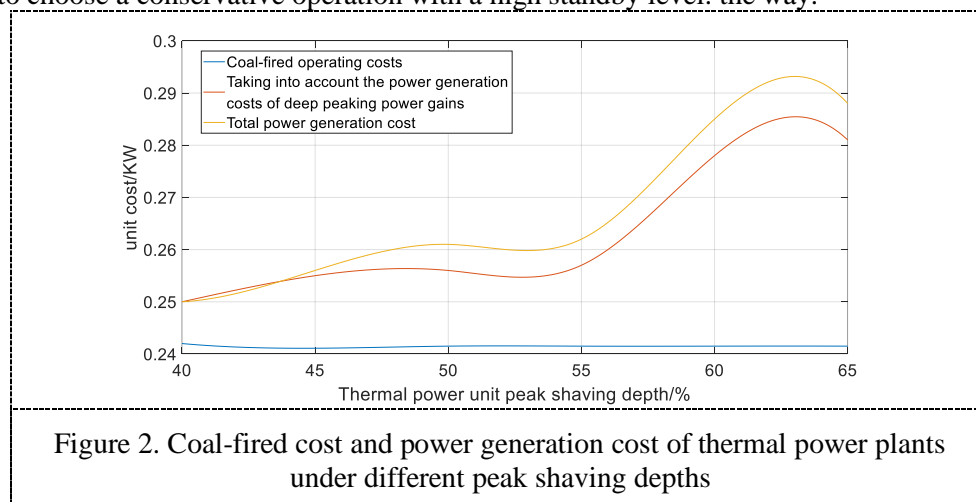


Figure 2 shows the coal-fired operating costs and total power generation costs of thermal power units at different peaking depths. It can be seen from the figure that with the increase of peaking depth, the coal-fired operating costs do not change much, and the unit power generation costs of thermal power enterprises are large. improve. Comparing Figure 1, it can be seen that the main reason for the increase in total power generation cost is the increase in fuelling costs and wear costs. It can be seen that even considering the power consumption of the thermal peaking of the thermal power unit, the overall economic benefit of the thermal power unit is still reduced. If the risk of boiler accidents involving the deep peak peaking is taken into account, the thermal power enterprises will be more inclined to choose a conservative operation with a high standby level. the way.



According to China's current policy, the purchase price of wind power and thermal power by the power grid is the on-grid price of thermal power, and the difference of wind power on-grid price is subsidized by the state. Therefore, the income of wind power enterprises consists of two parts: power purchase cost and national price difference. The wind power enterprise's revenue is proportional to the wind power utilization rate. With the increase of peaking depth, the national price difference compensates for the proportion of wind power enterprises' income. It is obvious that wind power enterprises are the most direct profiteers of thermal power plant deep peaking.

In the DPRO phase, there are positive and negative impacts on energy efficiency. On the one hand, oil injection and steady combustion increase the unit's fuel consumption and fuel pollutant emissions. On the other hand, the unit coal consumption, coal-fired pollutant emissions and abandoned air volume remain. It is decreasing, so the energy efficiency based on the expected output increases first and then fluctuates. From a social point of view, the energy efficiency of the power system based on the expected output does not maintain a monotonous increase with the peaking intensity of the thermal power unit. The optimal energy efficiency point based on the expected output also occurs when the peaking depth is 54%.

6. Conclusion

According to the operating state and energy consumption characteristics of thermal power units, this paper proposes a peaking energy cost model for different stages of thermal power plants. An economic dispatch model of power system with priority of wind power is established, and a power efficiency model based on coal consumption and power output based on expected output is proposed. Through the analysis of a typical 10-machine system, the economics of the thermal power plant deep-peak peaking scheduling scheme are analysed from thermal power enterprises, wind power enterprises and society. The following conclusions are obtained.

For thermal power enterprises, deep peak shaving is not economical; under the current compensation standard, even if the thermal power generation and compensation of thermal power plant peak diversion are taken into account, the overall economic benefits of thermal power units are still reduced; under the conditions of large-scale wind power grid connection, With the increase of peaking depth, the coal-fired cost of thermal power enterprises has not changed much, but the power generation cost has increased. The increase is mainly affected by the oil injection cost and wear cost during the deep peaking process. If the deep peaking process is taken into account The risk of accidents undertaken by the China National Thermal Power Corporation, the thermal power companies did not have the willingness to actively adjust the peak.

The deep peak shaving of thermal power units is obviously beneficial to wind power enterprises, but it does not always improve the energy efficiency of the entire power system. When considering only the economic and environmental protection of power production, with the increase of the peak intensity of thermal power, the energy efficiency of the power system fluctuates and does not increase with the peaking depth, but in the DPRO phase, the system energy efficiency will When the government's industrial-oriented expectations for new energy are taken into account, as the peaking depth increases, the energy efficiency of the power system shows a monotonous upward trend, which is optimal at 54% of PN, and the energy efficiency of the system after using DPRO. Significant decline. Therefore, comprehensive multi-factors, thermal power plant deep peaking control is more suitable in the DPRO stage, which can ensure the smooth promotion of the government's wind power priority dispatching policy, the improvement of social energy efficiency, and ensure that the economic interests of thermal power and wind power enterprises are relatively balanced.

From the simulation results, the existing deep peak shaving compensation standard is not enough to compensate for the deep peak shaving loss of the thermal power unit, and to encourage the thermal power enterprises to actively adjust the peak. In order to promote the consumption of new energy such as wind power, it is an effective plan to properly compensate the deep peaking unit.

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