Determination Method of Economic Maintenance Cycle on Steam Turbine Generator Unit

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Abstract. In view of the current situation of frequent wide load regulation and long-term ultra-low load operation of coal motor units under the new power system, this paper established the calculation model of the added value of energy consumption cost of steam turbine generator units, and put forward the method of taking the added value of energy consumption cost, maintenance cost and power supply benefit loss as the maintenance cost, and taking the maintenance interval corresponding to the lowest maintenance cost per unit power generation as the economic maintenance cycle, Thus, considering the difference of performance degradation law of different units, the maintenance cycle was determined pertinently. The method was applied to a 600MW unit, and the influence of different maintenance cycles on operation cost was analyzed.

Keywords: steam turbine; wide load; energy consumption cost; maintenance economy; maintenance cycle

1 Introduction

There are usually three methods to determine the maintenance cycle of turbine generator sets. The first method is to determine the maintenance cycle according to the number of operating calendar days, such as the electric power enterprise industry standard DL/T 838-2017[1], which stipulates the A-class maintenance interval of imported turbine generator sets as 6~8 years and the A-class maintenance interval of domestic turbine generator sets as 5~7 years, etc. 2The third one is to determine the maintenance cycle according to the economic benefits[3], which takes the loss of power generation, maintenance costs and benefits during the maintenance of the unit as the economic index, and the maintenance interval corresponding to the optimal comprehensive economic benefits as the The maintenance interval corresponding to the best overall economic efficiency is used as the maintenance cycle. Other methods of determining the maintenance cycle[4-8] are basically based on the further optimization or synthesis of the above three methods.

With the goal of "double carbon" and the new power system, the power supply structure has changed profoundly. The peaking attribute of coal-fired thermal power units has become more and more prominent. Frequent wide load regulation and long-term ultra-low load operation have become the norm. The operating condition has deviated

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from the design condition, and the heat consumption rate of turbine generator units has changed with the operating time. In paper [9], a risk calculation for the power plant was performed to assess the potential economic losses related to two scenarios (probable and worst-case). Andrzej et.al[10] propose the development of a methodology for the prediction of crack propagation and the fatigue process for the identified areas of the steam turbine rotor, which is then used as a part of a maintenance strategy based on risk analysis. In this paper, we propose a method to determine the economic maintenance cycle, taking into account the change of the thermal consumption rate of turbine generator sets under various operating conditions with the operating hours, and taking the increase of energy consumption cost as the key factor to determine the economic maintenance cycle, which can more accurately reflect the deterioration of the performance of turbine generator sets under wide load operation, and is an effective way to reduce the unit maintenance cost.

2 Calculation method of operating cost increase

For the purpose of economic analysis, the operation cost increase value proposed in this paper refers to the loss of production efficiency due to the increase of energy consumption level and maintenance shutdown during a maintenance cycle, which mainly includes three aspects: firstly, the energy consumption level of the turbine gradually increases with the increase of operation time, which brings about the increase of energy consumption cost. The second aspect is the loss of revenue due to the unit stopping power supply during the maintenance period. The third aspect is the direct costs of maintenance, including material and labor costs. These three aspects reflect the impact of different overhaul and maintenance timing on the unit economy, and are the main factors in determining the economic overhaul cycle.

2.1 Calculation method of added value of energy consumption cost

Under the new power system, the peaking characteristics of thermal power units are more prominent, focusing on two aspects: firstly, the utilization hours of thermal power units are decreasing year by year. Secondly, low load or even ultra-low load operation has become the norm. The turbine operates in non-design conditions for a long time, and its performance changes play a key role in determining the maintenance cycle.

After the new unit or the overhaul unit is put into operation for the first time, with the growth of operating time, the heat consumption rate of the turbine under each operating condition usually has a tendency to gradually increase. The increase in operating cost due to the increase in turbine heat consumption rate is used as a performance indicator to determine the maintenance cycle, which can fully reflect the influence of the turbine performance deterioration law on the maintenance cycle, so that the maintenance cycle can be formulated in a targeted manner according to the specific turbine thermal performance characteristics. Generally speaking, for units with rapid increase in heat consumption rate, it is advisable to shorten the maintenance cycle to avoid rapid increase in energy cost. For units with stable heat consumption rate, the maintenance cycle can be extended to reduce the maintenance cost per unit time and the loss of power generation revenue. The heat consumption rate of the turbine is related to the load and operating time of the unit, and its function relationship can be expressed by equation (1).

$$h = h(p, t) \tag{1}$$

In the formula（1）, h is the unit heat consumption rate, and the unit of the parameter h is kJ/kWh; $h(p, t)$ is a function related to the unit load p and operation time t.

Then, the value of the increase in energy cost due to the increase in turbine heat consumption rate can be expressed by equation (2).

$$E_Q = \int_0^T \int_0^p [h(p, t) - h(p, t_0)] dpdt \tag{2}$$

In the actual operation of the unit, the heat consumption rate of different loads and the change law of heat consumption rate with operating time are different, and it is difficult to solve the specific function of formula (1). In engineering applications, several load points can be identified within the operating load variation range of the unit, and the variation law of heat consumption rate with operating time can be obtained for each load point, so that formula (1) can be converted into a unitary function for easy solution, and the increase in energy cost due to the increase in heat consumption rate of the turbine can be shown in formula (3).

$$E_Q = \sum_i p_i \int_0^T [h(p_i, t) - h(p_i, t_0)] \tag{3}$$

In the formula(3), $h(p_i, t)$, $h(p_i, t_0)$respectively, when the load is p_i, the heat consumption rate as a function of operating time and the heat consumption rate of the new unit or the overhauled unit after the first commissioning.

Eq. (3) is a simplified algorithm of Eq. (2), both reflecting the increased value of the unit's energy cost due to the growth of the turbine heat consumption rate with operating time, which reflects the impact of the turbine thermal performance deterioration on the operating cost and provides a quantitative basis for the determination of the overhaul timing. For further simplification, the average heat consumption rate of a load point over a period of time and the operating time of the load can also be used to obtain the increase in energy consumption cost using a scatter function.

After the change of heat consumption rate of each load point with operating time is determined, the increase of energy cost due to the increase of heat consumption rate of the turbine in the whole operating load section can be obtained by the method of clustering. For example, if a unit is operated between 30% and 100% THA load, every 10% THA load can be used as a load point, and 5% THA fluctuation in load can be clustered in one load point, so that the increase in energy cost due to the increase in heat consumption rate of the turbine in the full operating load section can be obtained.

In order to further analyze the connotation of the added value of unit energy consumption cost caused by the increase of heat consumption rate, a 600MW unit is taken as an example to clarify that the rated load of the unit is the change law of steam turbine heat consumption rate with running time under 100%THA, as shown in figure 1. In the figure, the area enclosed by the change rule curve of the heat consumption rate of the load, the straight line of the initial value and the running time is the added value of the energy consumption cost, which reflects the influence of the deterioration of the thermal performance of the steam turbine on the running cost. As can be seen from figure 1, during the same running time, when the heat consumption rate increases rapidly, the energy consumption cost increases rapidly. When the heat consumption rate changes gently, the energy consumption cost increases slowly. Similarly, the change rule of heat consumption rate of other load points with the running time can be obtained, and then the cumulative increase of energy consumption cost caused by the increase of steam turbine heat consumption rate can be obtained according to the running time of each load point in a specific time period.

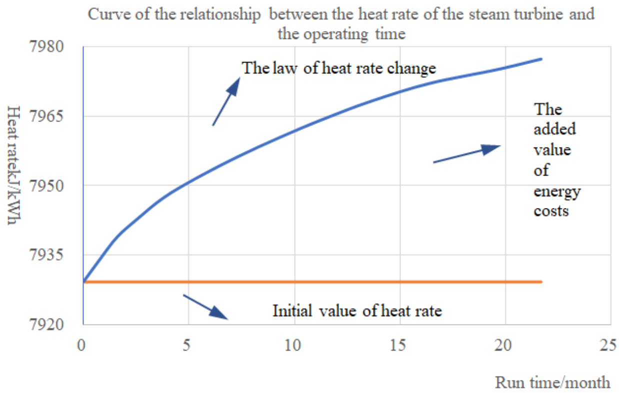

Fig. 1. Schematic diagram of the added value of energy consumption costs

2.2 Calculation method of power supply revenue loss

Loss of power supply revenue refers to the profit loss due to the stoppage of power supply during unit shut down for maintenance. Since the regular labor cost and financial cost of the enterprise are basically unchanged during the maintenance period, the supply profit refers to the difference between the feed-in tariff and fuel cost. The loss of supply revenue during the maintenance period has a clear economic meaning as the increase of operating cost, which can be calculated by equation (4).

$$C_q = Q_m\left(C_g - C_p\right) \quad (4)$$

In the formula (4), C_q is the value of power supply revenue loss, and the unit of C_q is Yuan. Q_m is the power supply during the maintenance period, and the unit of Q_m is kWh. C_g is the feed-in tariff, and the unit of C_g is Yuan/kWh. C_p is the cost of coal consumption for power supply, and the unit of C_p is Yuan/kWh.

Since C_p is related to the energy consumption level of the unit, the supply load and the price of standard coal, its calculation method can be expressed by equation (5).

$$C_g = A \cdot \sum_i b_i \cdot p_i \cdot T_i \quad (5)$$

In the formula (5), A is the price of standard coal, the unit of A is Yuan/g. b_i is the power supply when the unit load is p_i, and the unit of b_i is g/kWh. T_i is the power supply time when the unit load is p_i.

From equations (4) and (5), it can be seen that the loss of power supply revenue during unit shut down and maintenance is related to the length of maintenance, the load rate and the unit profit. The load rate and the unit profit of a specific unit are determined, so the length of maintenance is the main determinant of the loss of power supply revenue. The longer the maintenance time, the greater the loss of power supply revenue.

2.3 Inspection cost calculation method

Inspection costs usually include labor and material costs, which are determined separately according to the different types of inspection, and the calculation method can be expressed in formula (6).

$$C_m = C_a + C_c \tag{6}$$

In the formula (6), C_a is the labor cost, and the unit of C_a is Yuan. C_c is the material cost, and the unit of C_c is Yuan.

Different overhaul levels correspond to different unit overhaul scale, out-of-service time and different overhaul costs. Existing coal-fired power plants generally adopt the method of fixed value according to the unit capacity and local price level to determine, such as the maintenance cost of Class A steam turbine of a 600 MW unit of a power plant is about 4 million yuan.

3 Methods for determining economic overhaul intervals

The economic maintenance cycle mentioned in this article refers to the maintenance interval corresponding to the minimum corresponding maintenance interval in which the sum of the added value of the turbine's energy consumption cost, the loss value of power supply revenue and the maintenance cost is converted to the minimum increase value of operating cost per unit power supply during the maintenance cycle.

The difference in the economic maintenance cycle of steam turbine generator sets mainly has the following three aspects. First, the heat consumption rate level of the steam turbine gradually increases with the increase of operating time, and the energy consumption cost per unit of power supply gradually increases when converted to the maintenance cycle. Second, with the increase of operating time, the power supply increases accordingly, and the cost of unit power supply during the maintenance period is gradually reduced when converted into the cost of the unit power supply during the maintenance cycle. Third, with the increase of operating time, the cost of maintenance is gradually reduced by converting to the cost of unit power supply in the maintenance cycle.

The calculation of the increase in operating cost per unit of power supply can be expressed in equation (7).

$$C_b = \frac{A \cdot E_Q + C_q + C_m}{Q_T} \tag{7}$$

In the formula (7), Q_T is the amount of power supplied in one maintenance cycle, and the unit of Q_T is kWh.

Through real-time monitoring or performance test to determine the change law of steam turbine heat rate with operating time and load, the relationship between the added value of energy consumption cost and the change of operating time can be obtained. Then convert the loss of power supply revenue and maintenance costs to the change relationship between the cost per unit of power supply and the operating time, and the change law of C_b with the operating time can be obtained. When the C_b reaches the minimum value, the corresponding operating interval is the economic maintenance cycle of the turbine-generator set.

4 Analysis of Calculation Example

A newly-commissioned 600MW unit is scheduled to carry out A-level maintenance every 8 years. According to the actual operating load range of the unit, to simplify the calculation process, the increased value of energy cost is solved according to Equation (3). First, according to the unit operation history data, the load range is determined to be between 25%-105% THA, and the operation interval is divided into levels, which can be divided into 30% THA working condition, 40% THA working condition, 50% THA working condition, 60% THA working condition, 70% THA working condition, 80% THA working condition, 90% THA working condition and 100% THA working condition. Then, the actual Then, the operating hours of 25%-35% THA, 35%-45% THA, 45%-55% THA, 55%-65% THA, 65%-75% THA, 75%-85% THA, 85%-95% THA, 95%-105% THA load range are clustered into 30% THA condition, 40% THA condition, 50% THA working condition, 60% THA working condition, 70% THA working condition, 80% THA working condition, 90% THA working condition and 100% THA working condition. Finally, the average value of heat consumption rate of each working condition and its operating hours per year, as shown in Table 1, are used to calculate the cumulative increase of energy consumption cost for this working condition.

Table 1. Statistics of operating hours of each load of the unit in the past years

Commissioning time n / Running hours h / Load range	1	2	3	4	5	6	7	8	9
25~35%	10	15	17	21	56	86	106	117	118
35~45%	13	12	18	65	235	657	1002	1032	987
45~55%	1967	1816	1767	1754	1846	1706	1901	1837	1678
55~65%	976	1065	978	1554	1508	1175	812	856	768
65~75%	978	897	1033	965	867	854	541	537	657
75~85%	1879	1785	1578	1356	1278	1108	1089	986	1178

85~95%	809	1064	1356	967	806	731	609	615	867
95~105%	844	803	745	756	712	698	630	880	1080

The operating hours of each load section of the statistical unit can be used to calculate the increased value of energy cost according to the actual operation of the unit, and the relationship curve of the cumulative value of the increased value of energy cost of the unit calculated according to Equation (3) with the change of the operating hours is shown in Figure 2.

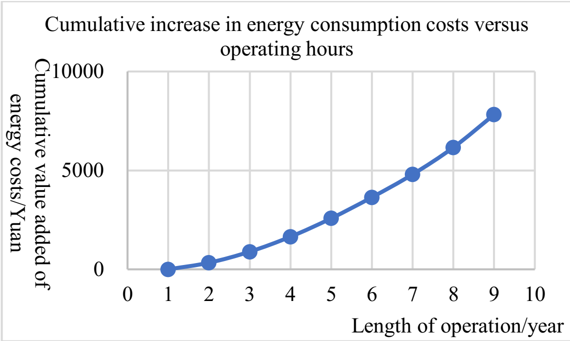

Fig. 2. Cumulative increase in energy cost of the unit versus operating hours

From Figure 2, it can be seen that the energy consumption cost of the unit grows faster and faster with the growth of operation time. The shorter the maintenance period, the lower the increase of energy consumption cost; the longer the maintenance period, the higher the increase of energy consumption cost.

Further, the length of the turbine A-level overhaul of the unit is 40 days, and the loss of power supply revenue during the shutdown period is solved by equation (4) according to the calendar year feed-in power, electricity price and the cost of standard coal; according to the local price level, the cost of the turbine A-level overhaul of the unit is fixed at 4 million yuan, and the relationship between the increase in operating cost per unit of power supply and the length of operation is obtained according to equation (7) as shown in Figure 3.

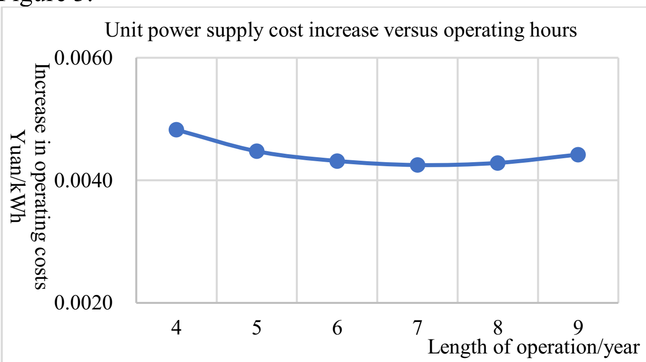

Fig. 3. Relationship between the increase in operating cost per unit of power supply and operating hours

From Figure 3, it can be seen that the unit has the lowest increase in operating cost per unit power supply in the seventh year after the unit is put into operation, which is an economic maintenance cycle. According to the power supply volume and power supply revenue loss in the past year, when the A-level maintenance is implemented in the fifth or sixth year, the operating cost will increase by 3.33 million yuan and 1.18 million yuan. When the A-level overhaul is implemented in the 8th or 9th year, the operating cost increases by RMB 830,000 and RMB 4.56 million.

5 Conclusion

(1) This paper proposes a method to determine the economic overhaul cycle of turbine generating units based on the increased value of energy consumption costs, loss of power supply revenue and overhaul costs, and calculates through actual case data that the conventional scheduled overhaul cycle is not an economic overhaul cycle.

(2) Since the systems and equipment of thermal power plants are an organic whole and usually carry out maintenance at the same time, the method of determining the economic maintenance cycle of the whole thermal power plant can be further extended to include the impact of boiler efficiency and plant electricity consumption rate on energy cost.

(3) The economic-based maintenance cycle proposed in this paper, in practice, should take into account the impact of equipment reliability to determine the reliability maintenance cycle of equipment. When the reliability maintenance cycle is longer than the economic maintenance cycle, the maintenance plan can be determined according to the economic maintenance cycle. When the reliability maintenance cycle is shorter than the economic maintenance cycle, for the safety of equipment operation, it is advisable to determine the maintenance plan according to the reliability maintenance cycle.

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