The Research of Utilization Hours of Coal-Fired Power Generation Units Based on Electric Energy Balance

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Abstract. With grid-connected scale of clean energy such as wind power and photovoltaic power expanding rapidly and cross-province transmission scale being bigger, utilization hours of coal-fired power generation units become lower and lower in the context of the current slowdown in electricity demand. This paper analyzes the influencing factors from the three aspects of demand, supply and supply and demand balance, and the mathematical model has been constructed based on the electric energy balance. The utilization hours of coal-fired power generation units have been solved considering the relationship among proportion of various types of power installed capacity, the output rate and utilization hours. By carrying out empirical research in Henan Province, the utilization hours of coal-fired units of Henan Province in 2020 has been achieved. The example validates the practicability and the rationality of the model, which can provide a basis for the decision-making for coal-fired power generation enterprises.

1. Preface
The annual utilization hours of power generation equipment are the operating hours of unit generating capacity under the rated capacity of power generation units, which is an important index to measure the utilization level of power generation equipment and the situation of power supply and demand. With the economy entering the new normal, energy and electricity demand has entered a low growth stage. And the utilization hours of coal-fired power generation units become lower and lower. Since the decentralization of project approval power and the increase of excessive profits of coal and electricity caused by the decline in coal prices, the trend of coal and electricity investment has been increasing since 2015, and there are excess risks in coal and electricity production capacity. Therefore, it is necessary to analyze the main factors influencing the utilization hours of coal-fired power generation units. The rapid development of wind power, photovoltaic and other new energy sources and grid-connected scale expanded year by year have produced a certain "substitution effect" on coal and electricity, at same time the scale of foreign power to expand has also produced "crowding out effect" on coal and electricity. It is necessary to sort out the relationship among proportion of various types of...
power installed capacity, the output rate and the utilization hours from the perspective of electrical balance and put forward the method of solving the utilization hours of coal-fired power generation units.

2. The main factor of influence

On the whole, the utilization hours of coal-fired power generation units is mainly affected by the three aspects of power demand, supply and demand and demand balance.

Demand side. Economic transformation and industrial structure upgrade lead to changes in power grid load characteristics. In the overall electricity structure, when the industrial users with more stable load increase rapidly, the utilization hours of coal-fired power generation units is higher. When the users of third industries and residents with obvious characteristics of peak and valley rise faster, they will pull down the utilization hours of coal-fired power generation units to some extent.

Supply side. In the context of energy transformation, the rapid development of clean energy power generation, the scale of cross regional electricity trading has been expanding. From the point of view category, The performance of the "peak-filling and valley-filling" will optimize the load characteristic curve and improve The utilization hours of coal-fired power generation units; wind power, photovoltaic and other new energy output instability, large load time need to provide reliable standby coal and small load time need to peak peaking, squeeze the coal power generation space. The trans regional electricity transaction has realized the large-scale optimization allocation of resources, and provided clean and reliable power guarantee for the receiving end provinces. When the power supply and demand is loose, the electric power outside the district will squeeze the end of the coal-fired power generation space; when the power supply is tight, the electric power outside the district has little effect on the utilization hours of coal-fired power generation units.

Supply-Demand balance. When the coal power installed capacity surplus, the output rate of the coal-fired power unit will decrease when the maximum load is reached, and correspondingly the utilization hours of coal-fired power generation units will be reduced. On the contrary, the utilization hours of coal-fired power generation units will rise when the coal power installed is shortage.

3. The balance of electricity

Starting from the balance of electric energy, the analytic expression of the utilization hours of coal-fired power generation units can is deduced.

Taking into account the balance of electricity, the total electricity consumption of the target year $E_C$ should be balanced with the power output of each type of power supply and the input energy outside the district. That is:

$$E_C = \sum_{X=1}^{7} E_X + E_E$$

In the formula, $E_C$ is the total electricity consumption of the target year; $E_X$ is the power output of each type power supply of target, the subscript 1 represents the coal power unit, the subscript 2 represents the conventional hydropower unit, the subscript 3 represents the pumping unit, the subscript 4 represents the gas turbine unit, the subscript 5 represents the wind turbine, the subscript 6 represents the photovoltaic unit, the subscript 7 represents the nuclear power unit; $E_E$ is the net input electricity outside of the target year.

Taking into account the balance of electricity, the maximum power load of the whole society of the target year $L_S$ should be balanced with the output of each type of power supply and the output of power from outside. That is:

$$L_S = \sum_{X=1}^{7} P_X + P_E$$
In the formula, $L_S$ is the maximum power load of the whole society of the target year; $P_X$ is actual annual output of all types of units at the maximum load period of the whole year of the target year, subscript meaning identical (1); $P_E$ is the net input power outside of the target year. According to the definition of the unit utilization hours, the generating capacity of each type of power unit satisfies the following formula:

$$E_X = G_X \times H_X$$ (3)

In the formula, $G_X$ is unit installed capacity of the type; $H_X$ are the unit utilization hours of the type.

The actual output meets the following formula.

$$P_X = G_X \times \gamma_X$$ (4)

In the formula, $\gamma_X$ is the unit actual output rate of the type.

In order to simplify the analysis, the external power and the local power supply are analyzed equivalently. Especially for the receiving end of UHVDC, the external power transmission curve is generally stable and can be equivalent to a constant power supply. The equivalent power source is similar to a generator set and can also obtain the concept of the unit utilization hours and the output rate. For the net input electricity:

$$E_E = G_E \times H_E$$ (5)

In the formula, $G_E$ is the delivery scale of the electrical design or the planned transmission scale; $H_E$ are the utilization hours of external power. Generally, external power is not involved in peak shaving, and the utilization hours of it are higher, usually over 5000 hours.

For the net input power:

$$P_E = G_E \times \gamma_E$$ (6)

In the formula, $\gamma_E$ is the ratio of the actual transmission power capacity to the designed transmission capacity. Usually it is more than 90%.

Generally through the maximum load utilization hours of the whole society $H_S$, electricity $E_C$ and load $L_S$ will be linked. In order to highlight the research focus, the coal-fired power unit is particularly independent of the 7 types of power sources. Take the formula (3)—(6) into it and refine the expression of (1) and (2).

$$H_S = \frac{E_C}{L_S} = \frac{G_1 \times H_1 + \sum_{X=2}^{7} G_X H_X + G_E H_E}{G_1 \times \gamma_1 + \sum_{X=2}^{7} G_X \gamma_X + G_E \gamma_E}$$ (7)

In order to improve the applicability of the model, the formula is treated by means of unitary. The numerator and denominator of the formula (7) are divided by the sum of the power supply in this region and the external power.
\[ H_S = \frac{E_C}{L_S} = \frac{\alpha_1 + H_1 + \sum_{x=2}^{7} \alpha_x H_x + \alpha_y H_y}{\alpha_1 + \gamma_1 + \sum_{x=2}^{7} \alpha_x \gamma_x + \alpha_y \gamma_y} \] (8)

In the formula, \( \alpha_x = \frac{G_x}{\sum_{x=1}^{9} G_x + G_y} \), \( x = 1, 2, 3, \ldots, 7 \)

The utilization hours of coal-fired power generation units can be conclude from the follow formula.

\[ H_1 = \frac{(\sum_{x=1}^{7} \alpha_x \gamma_x + \alpha_y \gamma_y) + H_e - \sum_{x=2}^{7} \alpha_x H_x - \alpha_y H_y}{\alpha_1} \] (9)

From the formula (9) we can see that we can calculate the utilization hours of coal-fired power generation units by determining the proportion of other types of power and external power, the output rate and the utilization hours under certain maximum load utilization hours.

4. **Empirical research**

Taking Henan Province as an example, this method is used to estimate the utilization hours of coal-fired power generation units in 2020.

**Step 1:** Determine the maximum load utilization hours \( H_S \). Looking at "13th Five-Year", Henan is in the critical period of building a well-off society and forming a pattern of modernization. According to "Energy Development Plan of Henan Province in 13th Five - Year" , the total electricity consumption is about 376 billion kwh in 2020, the average annual growth rate of 5.5%. Considering the adjustment of the electricity structure, the maximum load of the whole society is 73.8 million KW, and the maximum load utilization hours of the province is 5100 hours.

**Step 2:** Determine the proportion of all types of power supply and external power scale.

Determine the install capacity of coal-fired power. According to the new situation of increasingly restrictive resources and environment, energy green and low carbon development, and the requirements of "on the convergence of Henan province in 13th Five-Year the coal-fire production scale of the letter ", during "13th Five-Year" the coal-fire production scale of Henan should be controlled in less than 8.32 million Kw and further reduce the coal-fire production scale. The project of 5.5 million kilowatts coal-fire is postponed to "14th Five-Year" and later. The Provincial Energy Bureau has reported to the national energy board for a total of 3.6 million kilowatts generating units put into operation in "13th Five-Year" period. After coordinated consideration, during 2017-2020 the new coal-fired power unit put into 4.7 million Kw and shut down decommissioning 6.38 million Kw. The province's coal-fired power installed capacity reached 59.96 million Kw by 2020.

Determine the install capacity of wind power and photovoltaic. Henan will continue to optimize the adjustment of energy structure, adhere to clean low-carbon, green development, increase the proportion of non-fossil energy consumption in "13th Five-Year" period. According to "Henan province energy development plan in 13th Five-Year " and combined with the audited access project scale, the province's wind power, photovoltaic installed capacity is expected to reach 6, 8 million Kw in 2020. Determine the capacity of external power. The absorbing external power capacity of Henan power grid increased from 13 million Kw to 24 million KW. Considering the new production factor of Qinghai DC, the external power will be balanced according to 16 million KW in 2020.

Considering the hydropower, pumped storage and gas stations and planning to reach the target installed capacity, the proportion \( \alpha_x \) of various types of power supply and foreign power scale. See Table 1.

**Step 3:** Calculate the output rate \( \gamma_x \). The output rate of each type of power supply should be analyzed according to the actual situation of heavy load in recent years, and the higher probability expected value of the output rate will be calculated.
Step 4: calculate the utilization hours $H_x$. In addition to coal-fire, the utilization hours of other types of units should be analyzed according to the power generation in recent years, and the higher probability expected values of the utilization hours will be calculated.

Step 5: the formula (9) is calculated by substituting parameters. The specific calculation table is as follows.

**Table 1. Calculation table of the coal-fire utilization hours**

| Supply type         | $\alpha_x$/% | $y_x$ | $H_x$ | $H_S$ |
|---------------------|--------------|-------|-------|-------|
| Coal-fired          | 66           | 88%   | 4433  |       |
| Conventional hydropower | 3    | 50%   | 2700  |       |
| Pumped storage      | 1            | 100%  | 1600  |       |
| Gas-fired           | 3            | 50%   | 2200  | 5100  |
| Wind power          | 7            | 10%   | 2000  |       |
| Photovoltaic        | 9            | 30%   | 1000  |       |
| External power      | 11           | 92%   | 5100  |       |
| Nuclear power       | -            | -     | 7000  |       |
| Total               | 100          | -     | -     |       |

The calculation shows that when the output rate of various types of units is at a reasonable level and the overall balance of power supply and demand, the utilization hours of coal-fired power generation units in Henan Province is about 4400 hours in 2020.

5. Conclusion

1. The utilization hours of coal-fired power generation units is mainly affected by three factors: electricity demand, supply and supply and demand balance. In the current electricity structure, the utilization hours of coal-fired power generation units decreased rapidly and at a low level is mainly due to the low proportion of secondary electricity consumption, high proportion of residents and the tertiary industry, and power supply and demand loose.

2. Based on the energy balance, the research model of the coal-fired utilization hours is established. According to the model, the utilization hours of coal-fired power generation units can be calculate by determining the proportion of other types’ power and external power, the output rate and the utilization hours under the condition of a maximum load utilization hour.

3. The empirical study of Henan verifies the practicability and rationality of the research model. When the output rate of various types of units is at a reasonable level and the overall balance of power supply and demand, the utilization hours of coal-fired power generation units in Henan Province is about 4400 hours in 2020.

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