Analysis of Combined Participation of Wind Power and Electric Heating in Power Supply System

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Abstract. In order to improve the serious situation of wind abandonment in the "Three North" areas, solve the problem of local consumption of large-scale wind power and improve the peak shaving capacity of power grid, this paper combines regenerative electric heating with wind power with anti-peak shaving characteristics, and analyses the benefits of power side and load side under the combined operation mode of wind power and regenerative electric heating from two aspects of cost and benefit. The analysis results show that the joint participation of wind power and electric heating in the power market can effectively "cut valley and fill peak" and promote wind power consumption. The benefit analysis theory proposed in this paper provides guidance for the research of joint operation scheduling optimization model.

Key words: Wind power; electric heating; peak shaving capacity.

1. Introduction

The "three north" areas in China are rich in wind resources, and the production and life in this area need heating in winter. Heating has the characteristics of high popularity and large scale, but due to the limitation of the policy of "fixing electricity by heat", the phenomenon of abandoning wind is more serious [1-2]. The regenerative electric heating uses the wind energy wasted at night to convert the electric energy into thermal energy and stores it to release heat when the power is cut off during the day to provide heating for users [3-4], if the regenerative electric heating is used properly, a good effect of "cutting valley and filling peak" and wind power absorption can be achieved, which creates conditions for the safe and stable operation of the system.

At present, relevant scholars at home and abroad have done relevant research on the operation of wind power consumption and regenerative electric heating system. Literature [5] puts forward the peak regulation means of bringing the thermal storage boiler into the power grid and managing it in the way of virtual power plant to bear part of the peak regulation power. Literature [6] puts forward an evaluation method of thermal storage heating running together with hydropower and wind energy to meet the load growth in the power grid. Through the case study of the regional power grid, it is pointed out that the carbon emissions trading system and wind energy can meet its future energy balance needs and play the
complementary role of all kinds of energy. Through the dynamic control of the thermal storage heating system, wind energy can be absorbed, which is particularly effective in reducing diesel consumption, thus reducing greenhouse gas emissions. Literature [7] considering the constraints of the heating network, the operation optimization modeling of the thermal storage heating system connected to the power system is carried out, and the influence of its cooperative operation with wind power on the power grid is analyzed.

To sum up, through the key link of heat storage and energy storage of regenerative electric heating, the acceptance of wind power in the power grid can be improved, the phenomenon of energy waste can be reduced, the load can be shaped, and the power generation at the trough can be improved. It alleviates the power generation pressure of the load peak, plays the role of "cutting valley and filling peak", and creates conditions for the safe and stable operation of the system. In this paper, as an adjustable load, combined with wind power with anti-peak regulation characteristics, this paper studies the operation benefits of the joint participation of regenerative electric heating and wind power in the power market, so as to provide a theoretical basis for follow-up research.

2. The joint operation mode of wind power and electric heating participating in the electricity market
Due to the different light and temperature in different periods of time and the change of wind speed in different parts of the interior of China, there is a relative change law of wind power generation. According to the change law of wind power generation at maximum load and minimum load, the peak regulation characteristics of wind power can be divided into three types: positive peak regulation, over peak regulation and reverse peak regulation. In the inland areas of China, where the natural wind height is more than 30m, in terms of wind speed, the wind speed is usually fast at night and slow during the day; in terms of wind power, the temperature at noon is the highest and the natural wind is the smallest, which is in the trough period of wind power generation. The temperature is the lowest at night and the natural wind is the heaviest, which is in the peak period of wind power generation. Therefore, most of the peak regulation characteristics of inland wind power generation are anti-peak regulation [8-10].

Thermal storage heating is an efficient and environmentally friendly heating method, which usually uses cheaper electricity to heat the regenerator to a higher temperature at night, and then releases the heat energy in the regenerator during peak power. The electric heating of the heat storage device has the characteristic of adjustable load, therefore, in a certain unit time, the users of the urban central heating system, under certain heat conditions, the power consumption of the electric heating system in different periods can be adjusted according to the need. The balance between heating and heat load is completed by the heat storage device, which can change the load difference between peak and trough, and achieve a certain degree of load shaping [11-12].

Because wind power generation often shows the opposite characteristics of peak power regulation, during the night load trough, the wind and wind speed are very strong, and the amount of wind power generation increases, which enlarges the difference between the peak and valley of the power grid load and creates great pressure on the peak regulation of the system, so the ability of the power grid to accept wind power is insufficient. The nature of heat storage heating is similar to the adjustable load, and the load power consumed can be adjusted according to the needs of the power grid, so as to play the role of peak regulation and frequency regulation, thus it can be seen that the load power consumed can be adjusted according to the needs of the power grid. The two have good complementary characteristics. In this paper, three sources of wind power, thermal power and power grid are set up on the power side, and the regenerative electric heating load is increased on the load side, and their joint operation optimization is used to improve the wind power consumption capacity of the power grid. The joint operation mode of wind power and thermal storage heating is shown in figure 1.
3. Benefit analysis of the joint participation of wind power and electric heating in the power market

3.1. Power side benefit analysis

3.1.1. Income analysis.

(1) The cost of peak load capacity can be avoided. It means that the participation of electric heating in the electricity market causes power users to reduce the peak load of the power grid by taking the behavior of off-peak power consumption during peak periods, replacing the corresponding installed capacity. reduce the batch notes for new units. Since multiple load resources can be regarded as reduced new installed capacity, the reduced additional installed cost can be used to indicate that the peak load capacity cost can be avoided.

\[ R_y = \Delta N_y \times I_j \]  
\[ \Delta N_y = e_y \Delta P_y \]

In the formula, \( R_y \) is the avoidable peak load capacity cost; \( I_j \) is the newly installed unit investment cost; \( \Delta N_y \) is the reduced peak load capacity due to the implementation of demand response, and the value of \( \Delta N_y \) can be obtained by multiplying the avoidable peak load power \( \Delta P_y \) by the avoidable peak load capacity coefficient \( e_y \), Its value is between 1.32 and 1.63).

(2) Avoidable fuel cost

It refers to the fuel cost saved by power users to reduce electricity consumption due to the participation of electric heating in the electricity market, which can be expressed in the following formula.

\[ R_f = W \times AC \]

In the formula, \( R_f \) is the avoidable fuel cost; \( W \) is the reduced electricity consumption by new users; \( AC \) is the marginal cost of fuel per unit of electricity.

(3) The abnormal start and stop cost of the unit can be avoided.

It refers to the abnormal start and stop cost of the unit due to the sharp change of load, which is reduced after the electric heating participates in the electricity market. In order to meet the requirements of load changes, it is necessary to start and stop power generation equipment for many times, which not only consumes extra energy, but also wastes time, and is easy to cause damage to the equipment.

\[ R_s = C_s \times I \]
In the formula, $R_i$ is the Abnormal start and stop cost of units; $C_r$ is the cost per unit start and shutdown; $I$ is the abnormal start-up and shutdown times of the unit.

(4) Avoidable compensation for environmental pollution

It means that power generation enterprises reduce the emissions of pollutants after the joint participation of wind power and electric heating in the electricity market, thus avoiding some of the costs used to compensate for environmental pollution.

$$R_i = Q \times b$$

In the formula, $R_i$ is the compensation for avoiding environmental pollution; $Q$ is the reduced emissions of pollutants; $b$ is the compensation for unit pollutants set by the government (the current standard of sulfur dioxide charge is 0.63 yuan / kg).

(5) Benefit of delayed construction of power supply

It refers to the benefits brought by the joint participation of wind power and electric heating in the power market, which makes the power system avoid or postpone the increase in capacity.

$$R_l = \Delta N_r \times \mu = \frac{i \times (1 + i)^t}{(1 + i)^2} - 1$$

In the formula, $\Delta N_r$ is the system can avoid peak load capacity; $\mu$ is the unit investment cost; $i$ is the benchmark interest rate; $t$ is the economic use cycle of delayed power supply.

(6) Improved utilization rate of power generation equipment

It refers to the degree of utilization of power generation equipment after the joint participation of wind power and electric heating in the electricity market because the load becomes relatively flat. In the total investment of power generation enterprises, the proportion of equipment investment is usually high. Therefore, the investment benefit of power generation enterprises is greatly affected by the utilization rate of equipment, and the increase of the utilization rate of equipment is equivalent to the reduction of power generation cost.

(7) Improved environmental efficiency ratio

Environmental efficiency ratio refers to the net output value produced by power generation enterprises for each discharge of 1m³ “three wastes” (waste gas, waste water, waste). The higher the ratio, the better the environmental benefit. The increased environmental efficiency ratio is a percentage, which is obtained by subtracting the environmental efficiency ratio of the previous year from the environmental efficiency ratio of the previous year.

(8) Reduced resource utilization

Resource utilization rate refers to the amount of raw materials and energy consumed per unit net output value, and the lower the ratio is, the better the utilization effect of raw materials and energy is. The reduced resource utilization rate is obtained by subtracting the current year's resource utilization rate from the previous year's resource utilization rate.

3.1.2. Cost analysis.

(1) Reduced revenue from electricity sales.

Refers to the reduced revenue from electricity sales on the generation side due to the joint participation of wind power and electric heating in the electricity market.

$$C_{NR} = W \times p$$

In the formula, $C_{NR}$ is the reduced revenue from electricity sales; $W$ is the reduced electricity sales; $P$ is the average electricity price.

(2) Cost and subsidy of system installation and maintenance

It refers to the depreciation, installation and other maintenance expenses of power-saving equipment on the generation side.

$$C_g = \frac{C}{n} + C_r + C_w$$
In the formula, $C_g$ is the power equipment discount; $C$ is the initial investment cost of multi-load support equipment responsible for power grid enterprises; $n$ is the depreciation life of equipment; $r_c$ is the maintenance cost; $w_c$ is the equipment installation and other maintenance expenses.

3.2. Load side benefit analysis

3.2.1. Income Analysis. The comprehensive income is divided into two parts: heating income $P_{hot}$ and auxiliary service benefit $P_{as}$, as shown in Formula (9) to Formula (11):

$$P_{inc} = P_{hot} + P_{as}$$  \(9\)

$$P_{hot} = m_{hot} \cdot S$$  \(10\)

$$P_{as} = \sum_{d=1}^{n} \sum_{t=1}^{r} m_{as} \Delta P_{eh-d}(d,t)$$  \(11\)

In the formula, $S$ is the heating area of regenerative electric heating. $m^2$; $m_{hot}$ is the heating charge, RMB / $m^2$.

3.2.2. Cost analysis. The cost of regenerative electric heating is divided into two parts: static investment cost and operation cost.

In the formula, $P_{pay,s}$ is the static investment cost; $P_{pay,o}$ is the operating cost.

The static investment cost mainly refers to the cost of allocating the initial investment cost $IC$ and the decommissioned salvage value $DC$ to the life period $N$ years (regardless of the time value characteristic of the capital), as follows:

$$P_{pay,s} = \left( IC - DC \right) \div N$$  \(13\)

$$IC = \lambda \left( C_{P_a,N} P_{eh,N} + C_{Q_a,N} Q_{eh,N} \right)$$  \(14\)

In the formula, $P_{eh,N}$ for the purchase of regenerative electric boiler total power rating; MW, $Q_{eh,N}$ for the purchase of total rated capacity of regenerative electric boilers; MW·h, $C_{P_a,N}$, $C_{Q_a,N}$ is the unit cost of regenerative electric boilers; Yuan / MW, yuan / MW·h, $\lambda$ is a constant.

The operation cost refers to the corresponding cost of electricity consumed by the operation of the regenerative electric boiler during the whole heating period, which is calculated as shown in the following formula:

$$P_{pay,o} = Q_{ab} \left( C_{agr} + C_{id} \right) + Q_{a} C_{a}$$  \(15\)

In the formula, $Q_{ab}$ and $Q_{a}$ are abandoned wind power and non-abandoned wind power consumed by regenerative electric heating, respectively, which are related to operating power $P_a(t)$, abandoned air power $P_{ab}(t)$ and heating power $H_{hot}(t)$ of regenerative electric boiler, MW; $C_{agr}$ and $C_{a}$ indicate the agreed electricity price and civil electricity price signed with the wind farm respectively, yuan / MW·h; $C_{id}$ represents the transmission and distribution cost of the power grid company, yuan / KW·h.

4. Conclusion

This paper mainly studies the operation mode of the joint participation of wind power and regenerative heating in the power market, and analyzes the operation benefits of each subject on the generation side and the load side from the point of view of cost and benefit. The research on the joint operation and
dispatching optimization model will be carried out in the future, and further deepen the study of the benefit model.

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