Construction of Heat Load Demand Quantitative Model for Clean Heating

Weiqi Zhang and Baosheng Chen

Abstract This paper fully considers the flexible response ability of thermal load and the potential of clean energy consumption, builds a quantitative model of thermal load demand for clean energy consumption, and takes a clean heating demonstration project as an example to analyze the economy of the waste air heat storage heating system. An example shows that its economic benefits can be greatly improved under this quantitative model.

Keywords Demand quantification · Electric heating load

1 Introduction

Heating is the largest energy consumption area, and heating accounts for about 50% of global final energy consumption. From the perspective of global energy consumption, the use of clean energy is becoming an important development trend. Renewable energy heating accounts for about 10% of global heating. The use of heating energy will become an important factor in restricting energy security, environmental governance, and ensuring social sustainable development [1].

In the current market environment where the rate of wind and light abandonment of new energy in the "three north" and other places in China is high, effective use of spot goods, increase of power generation, and increase of benefits are effective means for new energy enterprises to increase benefits. New energy spot trading can effectively reduce the wind and light rejection rate of new energy through market mechanism construction without increasing hardware investment. In addition, the traditional demand-side response resources have the potential to absorb clean energy. In addition to the traditional power load, the thermal demand response is also of scheduling value to the power system in the context of the deepening degree of electrothermal coupling. Therefore, taking full account of the flexible response capacity of thermal load and

W. Zhang (✉) · B. Chen
State Grid Ningxia Electric Power Co., Ltd., Economic and Technological Research Institute, Ningxia, China
e-mail: 1027383287@qq.com

S. Yadav et al. (eds.), *Energy Power and Automation Engineering*, Lecture Notes in Electrical Engineering 1118, https://doi.org/10.1007/978-981-99-8878-5_17

the potential of clean energy consumption, and building a spot power transaction oriented to clean energy consumption will be an important development direction of future power market transactions, and preliminary exploratory research has been carried out at home and abroad [2].

In recent years, the Chinese government has actively promoted the development and utilization of clean energy and formulated a series of policies and regulations to support the consumption of clean energy. While increasing the supply of clean energy, various forms of new energy supply technologies, such as combined heat and power, have also developed rapidly. In response to the current situation of new energy curtailment in areas such as the "Three North" region, many domestic enterprises and institutions have begun to explore the application of electricity spot trading to increase the utilization of clean energy. Among them, the Energy Internet Research Institute of Tsinghua University has achieved certain results in the field of clean energy trading. The Institute has realized the dual goals of clean energy consumption and energy conservation and emissions reduction by building an electricity market trading platform for clean energy consumption [3].

In addition, to further increase the consumption rate of clean energy, various fields in China are actively conducting research. For example, in the industrial field, multiple technologies have been applied to the recovery and utilization of heat energy to achieve efficient energy utilization by converting waste heat into electricity or direct heating. At the same time, many domestic enterprises are also developing smart heating systems to improve the flexibility of thermal load and the consumption rate of clean energy by establishing a heating management platform based on cloud computing, the Internet of Things, big data, and other technologies. In addition, multiple research institutions in China are actively exploring energy-saving technologies and management models for heating networks to improve the energy efficiency and clean energy utilization rate of heating systems in cities.

In summary, with the rapid development of clean energy and policy support, various sectors in China have begun to explore multiple pathways and methods for clean energy consumption. In the future, we have reason to believe that with continuous technological innovation and the improvement of market mechanisms, clean energy will become an important driving force for the development of China's energy industry and make greater contributions to promoting energy revolution and building a beautiful China.

In foreign countries, for the cost-risk-assessment of thermal load response, the literature [5] uses Markov chain Monte Carlo method to model the dynamic of thermal load, proposes a risk assessment method of thermal load, and verifies it. Literature [6] establishes a nonlinear model of multi-ring heat network based on graph theory and hydraulic calculation model, uses Newton method to solve the model, and judges the fault state of the system according to the actual heat gain of users or the indoor temperature of users, forming a risk assessment method considering heat load. For the response regulation strategy of thermal load, many studies have been carried out abroad mainly for the response optimization regulation of thermal load after participating in the market. Literature [7] and others put forward a structural framework of thermal load aggregation, and on this basis studied the optimal regulation strategy of thermal load response when participating in market regulation in the form of thermal load aggregator in the day-ahead market, realizing the minimization of energy costs and the flexibility planning of thermal load. The detailed population model of independent housing in Finland and the day-ahead market data of Nord Pool's Elspot are used for simulation verification. Literature [8] proposes a two-stage stochastic programming model for the flexible demand response of heat storage devices, which realizes the flexible thermal load demand response of the two heat storage forms of building material heat storage and hot water heat storage. For the research on thermal load—green energy trading mechanism and trading variety design, the document [9] continuously improves the renewable energy incentive policy, improves the mode of renewable energy participating in the electricity market, studies and proposes the electricity market 2.0, and improves the electricity market to adapt to the high proportion of new energy access. Literature [10] proposes corresponding micro-grid power market schemes for different scenarios combined with blockchain to solve the mutual aid transaction of local communities and meet the self-sufficiency of local power generation and consumption. In view of the business model of grid-thermal control platform, the literature [11] summarizes the research status of foreign countries using thermal load to absorb green new energy. The United States has developed rapidly in this field in recent years, and the installed capacity of cogeneration has accounted for about 7% of the total installed capacity of the United States. Japan's energy consumption is mainly a district heating system with electricity-heat system as the heat source. In Europe, the EU's cogeneration power generation has accounted for 9% of its total power generation (among which Denmark, Finland, and the Netherlands have reached more than 30%). However, many studies have remained on the development of cogeneration units, without combining the electricity-heat consumption method with the market, and without a clear business model oriented to the bilateral spot market, so that the demand, willingness, and value of both parties cannot be accurately grasped. As a result, power plants and users cannot trust each other, and the large-scale promotion of the electricity-heat consumption mode is hindered.

2 Construction of Demand Quantification Model

Electric heating load forecasting model:

$$P = P_B + P_W$$

where P is total electrical heating load requirement, P_B is primary electrical heating. P_W is an electrical heating load component which is sensitive to weather factors.

$$P_B(t) = \left[\sum_{t=1}^{24} (Cair\rho air NSH + \partial KA)(T_{\text{in}}(t) - T_{\text{out}}(t)) - Q_{\text{in}e} - Q_{\text{in}h}\right] / \eta_h$$

where, *Cair* is the specific heat capacity of air; ρair is the air density; N is air quantity, S is housing area, H is room height, $Q_{\text{in}e}$ is electric equipment; $Q_{\text{in}h}$ is the heat value of human body; ∂ is the temperature differential correction coefficient; K is the heat transfer coefficient of the housing. Tin (t) is the room temperature at t, T_{out} (t) is the outside temperature at t, T_{out} (t) is the outside temperature at t, and η_h is the energy transfer efficiency.

To increase the precision of electric heating load prediction, taking into account the effect of humidity on electrical heating load, the electric heating load prediction was revised by regression analysis, and the following equation was obtained:

$$P_W = \max\left(\frac{\Delta S_H}{23.10}, \frac{\Delta S_T}{39.43}\right) / \min\left(\frac{\Delta S_H}{23.10}, \frac{\Delta S_T}{39.43}\right)$$

where: ΔS_H is the sensitivity of electric heating load at the corresponding humidity, ΔS_T is the sensitivity of electric heating load at the corresponding temperature T.

Output model of regenerative electric heating equipment:

$$Q_h(t) = \eta_h \times P_h(t)$$

where, $P_{\text{h}}(t)$ is the power consumption of the thermal storage electrical heating installation. In this paper, the conversion efficiency of solid heat storage electric heating is 95–98%.

Most of the solid heat storage materials are MgO, which can be heated up to 800 °C, relationship between the common storage and temperature is common:

$$S_{\text{in}} = cm(T_2 - T_1),\ T_2 \leq 800\ ^\circ\text{C}$$

where: c is MgO specific thermal capacity; M is MgO weight; T1 is the temperature prior to the thermal storage of MgO; T2 is the thermal storage temperature of MgO. Among them, the relation of heat storage capacity and heating time is as follows:

$$S_{HS}(t) = (1 - \eta_{HS})S_{HS}(t-1) + (S_{\text{in}}(t) - S_{\text{out}}(t))$$

$$S_{\text{in}}(t) = Q_{\text{in}}(t)\eta_{\text{in}}$$

$$S_{\text{out}}(t) = Q_{\text{out}}(t)\eta_{\text{out}}$$

Here: S_{HS} (t) is the heat storage capacity of the thermal energy in the time t, η_{HS} is the heat storage loss ratio, and S_{out} (t) is the heat release; Q_{in} (t) is the heat storage power at t, and Qout (t) is the heat release power at t, η_{in}, η_{out} is the efficiency of heat storage and heat release of the heat storage tank.

Thermal storage electric heating meets the requirement of "big customers directly purchasing electricity." By negotiating directly with the wind farm, the discarded wind power is bought at the agreed price. The network charges only the transport and distribution costs, and the remainder is bought from the network at the time of use. The economic evaluation model of regenerative electric heating is presented in the formula.

$$P_{\text{sum}} = C_{jp} \sum_{i=1}^{n} Q_{\text{hot}}^{i} + C_{\text{hot}} S - P_{\text{pay.s}} - P_{\text{pay.r}}$$

where, S is the heating zone for regenerative electrical heating; C_{hot} is the heating charge; C_{jp} is the unit price for saving energy and reducing emissions; $P_{\text{pay.s}}$ Static investment cost means that the initial investment cost and the retirement residual value are allocated to N years' service life; $P_{\text{pay.r}}$ for the operating cost, the operating cost means the cost equivalent to the energy consumed by the regenerative electric boiler in the entire heating period.

3 Example Analysis

Based on an example of clean heating, this paper analyzes the economic performance of the waste air thermal storage heating system.

(1) Conditions for heating. The heating time is 181 days, the heating area is 200,000 m^2, the heating cost is 20.375 yuan/m_2, and the cost of energy saving and emission reduction allowance is O.
(2) Regenerative electrical heating system parameters. The regenerative electrical feeding system is composed of 9 electric boilers; Electrothermal conversion efficiency 95%; Heat loss of 5% of pipeline network; Static investment cost: 1 million, $N = 20$, initial investment of 22.5 million, remaining value 2.5 million;
(3) Additional parameters. The total installed capacity of the approved wind farm is 400 MW; the power transmission and distribution cost of the grid company corresponds to the Charge of 0.11 yuan/kWh.

There are two kinds of operating modes in the thermal storage electric heating system: full power heating at low time and full time heating mode with heat storage. The economical operating mode in the wind-down period, i.e., it starts when the wind farm abandons the wind. In the case of shortage of wind power, the power grid can be bought to satisfy the heating requirement (Fig. 1).

Different operating modes of regenerative electric heating system have different energy consumption. Because of the uncertainty of the abandonment of wind power, it is impossible to satisfy the demand of the thermal storage electric heating system. The power consumption of the thermal storage electrical heating system is illustrated in the diagram.

In these two modes, the thermal storage electric heating system directly buys and discards wind energy. Finally, the economic efficiency of the entire heating cycle is demonstrated. During the entire heating period, the total economic loss was

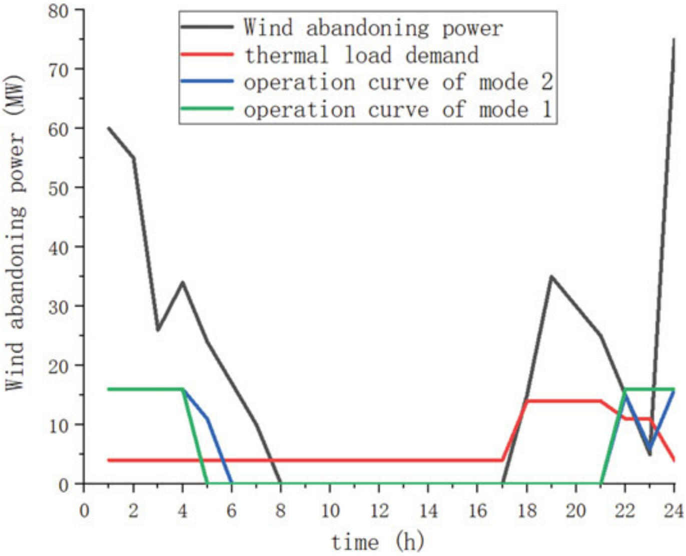

Fig. 1 Operating state diagram of regenerative electrical heating system

4.9493 million RMB and 5.1902 million RMB. It is mainly caused by the high cost of operation of electric power and the lack of relevant environmental subsidies. In the electricity market environment, the thermal storage electric heating system can further reduce operating costs and increase overall revenue through negotiation with the wind farm to lower the agreed price of wind power. For Mode 1, due to the low amount of power required to abandon the wind, even if the contract price for the abandonment of wind power is zero, the thermal storage electric heating system will suffer a loss. As for the second mode, as the power price is gradually lowered, the heat storage electric heating system is becoming profitable. When the contract price is set at 0.014 RMB/KW/h, the thermal storage electric heating system reaches its equilibrium point.

Gradually improving the power market will make it possible to take full responsibility for the operation of the electric heating system. In the case of 100% wind abandonment, the price of power is 0.045 yuan/kWh to break even. Given the state's concern about fog and thunder, the regenerative electric heating will be popularized, the energy conservation and emission reduction of the regenerative electric heating will be subsidized, and the economic efficiency will be greatly increased.

4 Conclusion and Suggestion

The power, thermal, and demand-side load combined absorption control technology studied in this paper has improved the rapid absorption capacity of the grid for intermittent renewable energy such as clean energy. In view of the above research, the following suggestions are put forward:

Establish the electricity heating price mechanism linked by the plant and the network, set up the electricity heating trading varieties by pre-listing or government guidance, and further reduce the electricity heating trading price. In the initial stage, wind power and other new energy will be the main energy source. In the later stage, the part above the minimum operation mode of thermal power units in the valley will enter the market and carry out transactions with electric heating users. The price shall not be higher than the marginal cost of the main thermal power units. Continue to implement the peak-valley electricity price policy on the user side, guide users to avoid peaks and valleys, increase the power load in the valley section, further reduce wind abandonment, and improve the utilization efficiency of thermal power units in the valley section. Combine the user categories of electric heating and retain the residential, general industrial, and commercial electric heating categories. Except for residential electric heating users (including schools, nursing homes, welfare homes, village committees, and other users who implement residential electric heating tariffs), other users are considered as general industrial and commercial heating users.

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