Design and research of electric heating as the core of energy system renovation of existing buildings

Weitao Liu*, FuqingWang, Xuze Zhang, Linguang Shi, Chenyang Zhao, Ruobo Chen

State Grid Tianjin Electric Power Company Chengnan Branch, Tianjin, China

Abstract. With the implementation of China's two-carbon strategy, how to achieve clean heating, especially the construction of a heating system with electricity as the core, has become a research hotpot in the industry. Among them, air source heat pumps, ground source heat pumps and energy storage have become important technical measures. In view of the capacity increase of urban heat exchange stations, combined with regenerative electric boilers and electricity price reform, this paper uses valley electricity for heat storage, and based on economic analysis, the municipal heat network is increased in flexibility and cleanliness, air energy, coupled energy storage clean and low-carbon heating transformation strategy.

1. Introduction

With the proposal of the "dual carbon" goal, clean and efficient energy use has become the mainstream of my country's energy development. In the field of heating, municipal central heating is the main body, and the demand is huge[1]. The urban heat exchange station, as the link of heat exchange between the primary heating network and the secondary heating network, plays an important role in improving the heating quality and heating efficiency[2]. However, at present, the municipal heat source is usually the cogeneration of thermal power plants for heat supply, which has high carbon emissions. At the same time, due to the complexity of the heat pipe network, the heat loss is about 10%-20%[3]. Combined with the current development trends such as clean heating, electricity is the main source. , based on new energy the new heating method has become the focus of the current energy transformation.Jiarong Dong[4] study on suitability of solid state electric heat storage in campus buildings in severe cold region.s

The introduction of electric heating equipment in urban heat exchange stations, on the one hand, realizes clean heating through electric-heat conversion, and can be used as a backup heat source to supply heat to the secondary heating network when the heat source fails, improving heating quality and efficiency; The heat supplementary equipment and the heat network jointly supply heat to the users, rationally utilize the grid electricity price and participate in the auxiliary service peak shaving market, and obtain benefits through price-based and incentive-based demand response, so as to realize the optimal operation benefit of the electric supplementary heat equipment.

2. Building energy system with electricity as the core

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2.1 Re-electrification of buildings

In response to the United Nations Sustainable Development Agenda, combined with the current background of energy conservation and emission reduction, the most urgent topic of architecture is how to rebuild the energy and material circulation system to reduce the burden on the environment. In the process of vigorously promoting near-zero energy buildings and building re-electrification, the building energy system will show a centralized-decentralized characteristic. There are not only large-scale distributed energy systems with large scale and centralized supply at the regional level, but also single-scale distributed energy systems. Small-scale distributed energy supply system with small scale and decentralized supply, which makes the integrated and optimized management of building energy system particularly important.

For regenerative electric boilers, on the one hand, the critical electricity price corresponding to the heat price under price-type demand response and the size of the grid peak-to-valley electricity price and the benefits obtained

* Corresponding author: Weitao.liu@tj.sgcc.com.cn

by participating in the peak-shaving subsidy in the auxiliary service market under the incentive-type demand response, on the other hand Considering the operation and maintenance cost of the regenerative electric boiler and the operation and adjustment cost of the primary heat network, and using the heat storage characteristics of the regenerative electric boiler, a control method is proposed, which can meet the heat load demand of users, the constraints of the equipment itself and the constraints of the grid. Under the circumstance, the simplex method in linear optimization is used to solve the problem, and the economical optimal control is obtained. The economical operation of electric boilers improves the economic benefits of electric heating equipment in heat exchange stations on the premise of ensuring clean heating.

2.2 Building energy system with electricity as the core

With the improvement of building energy-saving standards and the continuous increase of the proportion of clean electricity, promote efficient electrification application technology and equipment in the field of building energy use, use electricity when electricity is appropriate, and give full play to the advantages of electricity in building terminal consumption. Encourage the use of electric heating methods such as heat pumps to solve the new heating demand, guide the development of domestic hot water and cooking energy to electrification, and continuously improve the electrification rate of buildings.

The flexibility of building power load adjustment capability has been improved, bringing huge benefits to both the grid and users. The optimized operation scheduling strategy combined with the energy demand of the building and the load characteristics can greatly reduce the peak load of the building and relieve the pressure of the load increasing year by year. On the grid side, it can effectively reduce the peak-to-valley difference of the power load, improve the operating efficiency of the power system, and improve the power grid. On the power side, it can reduce the use of external energy by the building, which is conducive to improving the utilization rate of power equipment, reducing the cost of energy use by users, and reducing power consumption.

3. Additional Regenerative Electric Boiler and Control Method for Heat Exchange Station

3.1 Installation of regenerative electric boilers in urban heat exchange stations

Based on the current clean heating method, combined with electricity price reform and considering the economic benefits of valley price of electric, adding regenerative electric boilers in urban heat exchange stations, combined with smart heating for collaborative control, can increase the capacity of the existing heating system and reduce emissions, but also provides a model for the integration of green electricity and clean heating, as shown in Figure 1.

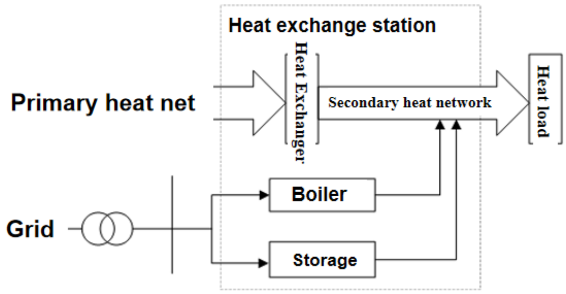

Fig. 1 Regenerative electric boiler equipment of urban heat exchange station

3.2 Coordinated control of regenerative electric boilers in urban heat exchange stations

The coordinated control of regenerative electric boilers in urban heat exchange stations involves electric boilers, electric heat storage devices, large power grids, primary heating networks, secondary heating networks and user heat loads. On the one hand, consider the size of the critical electricity price corresponding to the heat price under the price-based demand response and the grid peak-to-valley electricity price and the benefits obtained from participating in the peak-shaving subsidy in the auxiliary service market under the incentive-based demand response, on the other hand, consider the thermal storage electric boiler. The operation and maintenance costs and the operation adjustment cost of the primary heating network are met. Under the constraints of cooperating with the heating network to meet the user's heat load demand, the operation of the regenerative electric boiler and the power grid, the linear optimization method is used to control the direct heating of the regenerative electric boiler. The heat supply power, the heat storage power and the heat release power of the heat storage device realize the optimal economical working mode.

Among them, the thermal critical electricity price expression is:

$$\lambda_{tc} = \lambda_t * \eta * 0.0036 \quad (1)$$

In the formula (1), λ_{tc} is the heat price converted into the corresponding electricity value, yuan/kWh; λ_t is the heat sales price, yuan/GJ; η is the conversion efficiency of electricity. The power grid peak-to-valley electricity price and thermal critical electricity price ordering types include a total of 4 types：$\lambda_P > \lambda_u > \lambda_v > \lambda_{tc}$；$\lambda_P > \lambda_u > \lambda_{tc} > \lambda_v$；$\lambda_P > \lambda_{tc} > \lambda_u > \lambda_v$；$\lambda_{tc} > \lambda_P > \lambda_u > \lambda_v$。In practical applications, the relationship between grid electricity price and heat price always corresponds to one of four situations.

The regenerative electric boiler is used as an electric supplementary heat device, and the heat released by the boiler and the heat exchanged by the primary heat network through the heat exchanger together supply heat to the user to meet the heat load of the user:

$$Q_{pt} + Q_{st} = Q_u \quad (2)$$

In the formula (2), Q_{pt} is the heat power exchanged from the primary heat network to the secondary heat network, kW; Q_{st} is the supplementary heat power of the regenerative electric boiler equipment, kW; Q_u is the heat load demand of the user, kW. The specific mathematical expression is as follows:

$$Qu= qh*AC*10-3 \quad (3)$$

In the formula (3), q_h is the heating heat index, W/m2; A_c is the construction area of the heating building, m^2.

$$Q_{pt} = \rho \times c_p \times G \times \left(T_g - T_h\right) \quad (4)$$

In the formula (4), ρ is the density of the heating medium in the primary network, kg/m3; C_p is the specific heat capacity of the heating medium in the primary network, kJ/(kg·°C); G is the flow rate of the heating medium in the primary network, m3/h; T_g is the water temperature in the primary network, °C; T_h is the return water temperature of the primary network, °C.

$$Q_{st} = P_{EB} \cdot \eta_{EB} + \frac{1}{\eta_{ST-\text{out}}} \cdot Q_{ST-\text{out}} \quad (5)$$

In the formula(5), P_{EB} is the electric power consumed by the direct heating part of the electric boiler, kW; η_{EB} is the electric-heat conversion efficiency of the direct heating part of the electric boiler; Q_{ST-out} is the heat release power of the heat storage device, kW; η_{EB-OUT} is the heat release efficiency of the heat storage device.

The operation strategy of the regenerative electric boiler is:

(1) Electric boiler operation strategy

$$0 \le P_{EB} \le P_{EB}^{\max} \quad (6)$$

In the formula (6), $P_{EB}^{\max}$ is the maximum electric power allowed to be consumed by the direct heating part of the electric boiler, kW.

(2) Operation constraints of heat storage device

$$\begin{cases} W_{ST}^{t} = W_{ST}^{t-1} \cdot (1-\mu) + (Q_{ST-\text{in}} \cdot \eta_{ST-\text{in}} - \dfrac{1}{\eta_{ST-\text{out}}} \cdot Q_{ST-\text{out}}) \cdot \Delta \text{t} \\ 0 \le W_{ST}^{t} \le W_{ST}^{\max} \\ 0 \le Q_{ST-\text{in}} \le Q_{ST-\text{in}}^{\max} \\ 0 \le Q_{ST-\text{out}} \le Q_{ST-\text{out}}^{\max} \end{cases} \quad (7)$$

In the formula (7), W_{ST}^{t} is the heat stored in the heat storage tank of the regenerative electric boiler at time t, kWh; μ is the self-loss thermal energy coefficient of the heat storage device; $Q_{ST-\text{in}}$ is the heat storage power of the heat storage device of the regenerative electric boiler, kW; $\eta_{ST-\text{in}}$ is the Thermal efficiency; Q_{ST-out} is the maximum heat storage, kWh; $Q_{ST-\text{in}}^{\max}$ is the maximum heat storage power of the heat storage device, kW; $Q_{ST-\text{out}}^{\max}$ is the maximum heat release power of the heat storage device, kW.

(3) The grid constraints are:

$$U_{j.\min} \le U_j \le U_{j.\max} \quad (8)$$

In the formula (8), U_j is the voltage of the grid node where the regenerative electric boiler equipment is located, kV; $U_{j,min}$ is the minimum voltage value that the node can withstand, kV; U_{j-max} is the maximum voltage value that the node can withstand, kV.

3.3 The optimal economic working mode of the regenerative electric boiler in the urban heat exchange station

In the price-based demand response, by controlling the electrical disconnection of the regenerative electric boiler and the thermal disconnection of the heat storage tank, and using the price difference between the electricity price and the heat price, the economic benefits of electric supplementary heat are obtained; in the incentive demand response, by participating in the The peak-shaving auxiliary service market can obtain economic subsidies. In addition, considering the operation and maintenance cost of the regenerative electric boiler and the operation and adjustment cost of the primary heating network, synthesizing all the benefits and costs, the comprehensive target benefit function is:

$$\max L = \max(E_{\text{price}} + E_{\text{peak}} - C_{\text{maintain}} - C_{\text{regulate}}) \quad (9)$$

In the formula (9), L is the comprehensive income of the regenerative electric boiler; E_{price} is the electricity price difference income of participating in price-based demand response; E_{peak} is the subsidy income of participating in the peak-shaving auxiliary service market; $C_{maintain}$ is the operation and maintenance cost of the regenerative electric boiler; Cost; $C_{regulate}$ is the adjustment costs for the operation of the primary heat network; is the maximum objective function.

(1) Participate in price-based demand response electric heating spread income

$$E_{\text{price}} = \sum_{t=1}^{24} (\lambda_{\text{tc}} - \lambda_{\text{grid}}^{t}) P_{\text{grid}}^{t} \quad (10)$$

In the formula (10), P_{grid}^{t} is the electricity price in the unit period, Yuan/kW·h; $\lambda_{\text{grid}}^{t}$ is the electric power consumed by the regenerative electric boiler in the t period, kW.

(2) Subsidy income from participating in the peak shaving auxiliary service market

$$E_{\text{peak}} = \sum_{t}^{k} c_{peak}^{t} \times P_{\text{grid}}^{t} \quad (11)$$

In the formula (11), k is the auxiliary peak shaving period specified by the power grid; c_{peak}^{t} is the subsidy electricity price for the auxiliary peak shaving per unit period, Yuan/kW·h.

(3)Operation and maintenance costs of regenerative electric boilers

The regenerative electric boiler will generate additional operating costs when electricity is converted to heat and the heat storage tank stores and releases heat. The calculation formula for the operation and maintenance cost of the regenerative electric boiler is:

$$C_{\text{maintain}} = \sum_{t=1}^{24} c_{\text{ess}} \times Q_{ST-\text{in}}^{t} + \sum_{t=1}^{24} c_{\text{ess}} \times Q_{ST-\text{out}}^{t} + \sum_{t=1}^{24} c_{\text{eth}} \times P_{\text{grid}}^{t} \quad (12)$$

In the formula (12), C_{ess} is the unit power operation and maintenance cost of the energy storage part of the regenerative electric boiler, yuan/kW; C_{eth} is the unit power operation and maintenance cost of the electric-heat conversion part of the regenerative electric boiler, yuan/kW; $Q_{ST-\text{in}}^{t}$ and $Q_{ST-\text{out}}^{t}$ are the heat storage in the t

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period, respectively The heat storage power and heat release power of the heat storage device of the electric boiler, kW.

(4) Operation adjustment cost of primary heating network When the supplementary heat power of the regenerative electric boiler changes, the electric valve of the primary heating network also needs to be adjusted accordingly, so that the heat exchanged by the primary heating network matches the heat supplemented by the regenerative electric boiler. Corresponding adjustment cost will also be generated, which is proportional to the change of the supplementary heat power. Therefore, this paper introduces the adjustment cost coefficient of the primary heat network. The calculation formula of the operation adjustment cost of the primary heat network is:

$$C_{\text{regulate}} = K_{\text{regulate}} \cdot \left| Q_{\text{hs}}(t) - Q_{\text{hs}}(t-1) \right| \quad (13)$$

In the formula (13), $K_{regulate}$ is the adjustment cost coefficient of the primary heat network, Yuan/kW; $Q^{hs}(t)$ is the supplementary heat power of the regenerative electric boiler equipment at time t, kW; $Q_{hs}(t-1)$ is the supplementary heat power of the regenerative electric boiler equipment at time t-1, kW .

3.4 Distributed heating stations incorporating renewable energy

In addition, based on the assessment of renewable energy resources in the region, the site selection of regenerative electric boilers can be optimized, and the combination of solar thermal utilization, photovoltaic power generation, air source heat pump, etc. Low-carbon and clean transformation, as shown in the figure, will promote carbon peaking and carbon neutrality in clean heating and building heating industries.

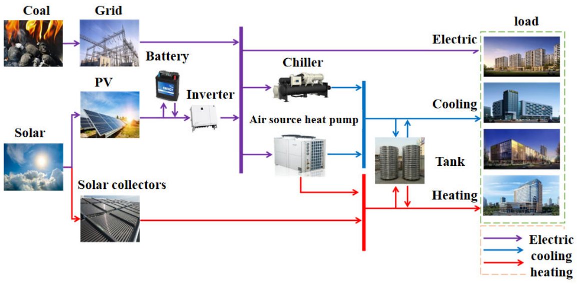

Figure 2. Distributed heating stations incorporating renewable energy

4. Conclusion

Each building can utilize the natural energy in a cascade according to its own resources and energy grade, so as to achieve the best efficiency of energy and reduce carbon emissions. The power system is an ultra-large scale nonlinear time-varying energy balance system. With the large-scale access of new energy sources, the operation mode of "source-following-load" has been fundamentally changed. The coupling of electricity and heat will improve the flexibility of electricity and increase the flexibility of heat grids. In a power system with an ever-increasing proportion of new energy sources, various forms of energy storage play a crucial role after a large number of distributed new energy sources are connected on the power side due to the huge randomness and volatility of new energy sources.

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References

1. HO Hiang Kwee. Towards “integrated energy systems” — challenges and directions [R]. Singapore: International Conference on Sustainable Energy Technologies, 2008
2. Guo Guanghua, Du Ying, Fan Yunpeng, et al. A review of research on integrated energy systems with electricity as the core [J]. Shandong Electric Power Technology, 2021, 48(8): 1-7
3. Han Wei, Multi-energy complementary multi-functional energy system and its integration mechanism [D]. Beijing: Graduate School of Chinese Academy of Sciences, 2006
4. Jiarong Dong, Study on suitability of solid state electric heat storage in campus buildings in severe cold region. Shenyang Jianzhu Univercity, 2019.