Intelligent Park Load Scheduling Optimization Method Considering Heat-Power Linkage

Zesheng Hu, Jun Lu, Xingxing Wang, Zhiqiang Xu, Gangjun Gong and Yun Wang

Abstract Aiming at the problem that the load peak-to-valley difference of the power system distribution network is high and the load volatility is large, this paper proposes an intelligent park demand response (DR) day-to-day scheduling strategy considering hybrid heating mode of heat-power linkage (HPL). Firstly, based on the analysis of the original load classification of the intelligent park, the intelligent park user load demand is divided into load replaced by heat (LRH) and load irreplaceable by heat (LIRH), and the energy consumption mode with flexible scale thermoelectric ratio is proposed. Then the minimum variance of the side load curve of the distribution network is taken as the goal, and the optimization model of the intelligent park load scheduling considering the HPL is constructed. The DR strategy considering the HPL is proposed. Finally, the rationality of the proposed scheme is illustrated by the calculation example. The results show that the load peak-to-valley difference and volatility are reduced, and the side load flexibility of the distribution network is enhanced.

Keywords Heat-power linkage · Intelligent park · Demand response

1 Introduction

With the extensive application of advanced Internet information communication and control technology in the energy system, deep integration and unified scheduling of energy through the energy Internet has become an important way to solve the energy crisis and environmental pollution [1, 2]. The demand response

Z. Hu · J. Lu (✉) · X. Wang · G. Gong · Y. Wang
School of Electrical and Electronic Engineering, North China Electric Power University, Beijing 102206, China
e-mail: lujun@ncepu.edu.cn

Z. Xu
State Grid Hunan Electric Power Co. Ltd., Changsha 410004, China

Y. Xue et al. (eds.), *Proceedings of PURPLE MOUNTAIN FORUM 2019-International Forum on Smart Grid Protection and Control*, Lecture Notes in Electrical Engineering 584, https://doi.org/10.1007/978-981-13-9779-0_64

strategy considering the linkage between heat and electricity can realize the efficient utilization of the thermal power resources in the intelligent park [3–5].

At present, domestic and foreign heat-power linkage systems mainly include electric and heat combined application in the reduction of renewable energy power fluctuations. Shao et al. [6] established the electric-thermal linkage scheduling model, and took the overall coal consumption in operation as the optimization objective, supplemented by the minimum wind abandoning volume, to realize the coordinated optimization operation of power system and thermal system and improve the capacity of wind power consumption. Lu et al. [7] puts forward a low-carbon economic scheduling model for integrated energy system, and establishes a comprehensive coordination model between heat storage and heat release rate of wind power with ultimate consumption and electric boiler power. Shi et al. [8] takes the minimum coal consumption as the objective function, establishes the optimal scheduling model, and realizes the optimal scheduling of wind abandoning and absorption in the electrothermal comprehensive energy system based on energy flow.

In this paper, the combined demand response strategy of heat and power considering thermal energy access is proposed, which transforms the energy use mode of the intelligent park into the combined energy supply of heat energy and electric energy. Firstly, this paper analyzes the electrical energy that can be replaced by heat energy in the original electric energy, and makes independent modeling for it. Then, this paper proposes the method of using power grid to supply the remaining electric energy, and carries out collaborative and interactive scheduling. Finally, this paper finds the best thermoelectric ratio by changing the thermoelectric ratio, and then obtains the optimal scheduling result, realizing the quantitative description of load response flexibility.

The following of this paper is organized as follows: Sect. 2 describes the framework of intelligent residential demand response. Section 3 introduces the optimization model and operating principle of the residential HPL energy system. A strategy solving process considering demand response and HPL is established in Sect. 4. Section 5 analyzes simulation results. The conclusion is drawn in Sect. 6.

2 Multi-energy Supply Strategy

2.1 Energy Scenario

The energy scenario in this paper is shown in the Fig. 1. In this paper, the load in the energy scenario can be divided into two types: (1) power load, which is supplied by the distribution side. This paper only considers the power supply from the same power supply company. It mainly includes base load which is necessary for residents' life and cannot be scheduled and replaced, meeting the minimum requirements of daily electricity consumption, typically represented by lighting, and

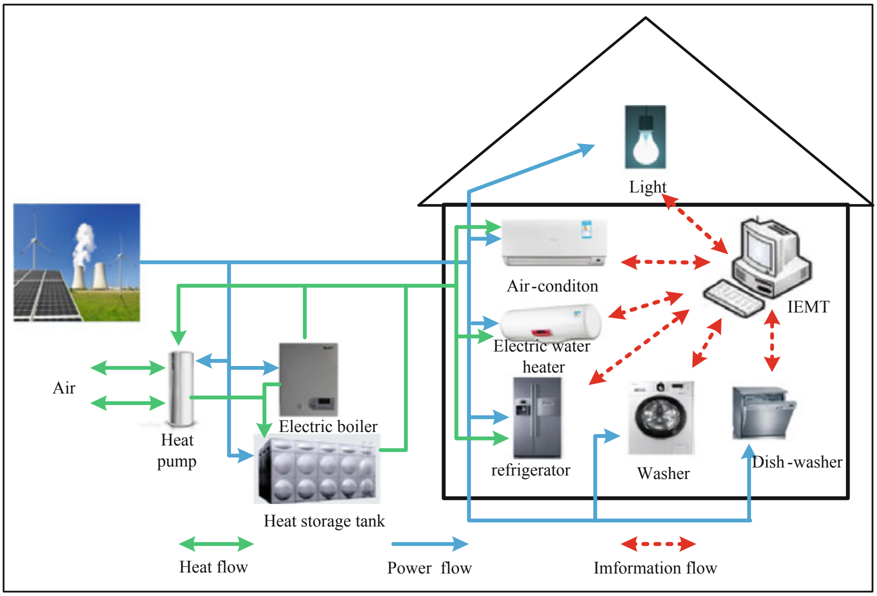

Fig. 1 Energy scenario diagram

dispatchable load which can be adjusted and the load usage can be interrupted, for example, the washing machine. (2) Heat load, which is provided by heat pump, electric boiler, etc. (the heat load considered in this paper does not include the residential heating in winter, only the load that can replace the electric energy with heat energy), mainly including the load provided by electric water heater, air conditioner and refrigerator.

2.2 *Residential Energy Strategy for Multiple Forms of Energy Supply*

In this part, a new energy utilization strategy is proposed under the new energy utilization scenario of the intelligent park with HPL. In this paper, the initial load is divided into two categories: heat replaceable load E_{in} and heat irreplaceable load E_{out}. Among them, the replaceable load can be divided into the heat load that participates in the dispatching and the heat load that does not participate in the dispatching according to whether or not they participate in the dispatching. The heat irreplaceable load can be divided into the base load and the dispatchable load. In this paper, the daily electricity consumption of residents is summarized as shown in Table 1.

Table 1 Household appliances electricity consumption

Type	Dispatchability	Whether can replace with heat load
Dish-washer	Yes	No
Air condition	No	Yes
Washing machine	Yes	No
Water heater	Yes	Yes
Refrigerator	No	Yes
Lighting and entertainment	No	No

The ratio of the participating heat load to the replaceable heat load is defined as the heat-power ratio B,

$$B = \frac{E_{in}}{P_{sum}} \times 100\% \tag{1}$$

where $P_{sum} = E_{in} + E_{\mathrm{out}}$ represents the replaceable load.

The heat-power ratio will change the dispatchable load involved in the demand response and affect the load curve. At this time, the power distribution side load is due to the residential power load and the electric energy consumed by the heat generation equipment and heat storage equipment. use, peak and valley difference can be reduced and volatility can be suppressed.

3 Mathematical Modeling

3.1 Objective Function

The objective function is the minimum load fluctuation on the grid side. In this paper, the day is divided into 24 moments, the total number of users is n, the user k has an electrical load of $I_k(\mathrm{t})$ at time t, and the electrical load of the heat pump and other equipment at time t is $J_k(\mathrm{t})$, then the total load at time t is $S_k(\mathrm{t})$, the total load of one day is $S(\mathrm{t})$. the average daily power load is $\overline{S(\mathrm{t})}$, and the objective function is as shown in the formula:

$$S_k(\mathrm{t}) = I_{\mathrm{k}}(\mathrm{t}) + J_{\mathrm{k}}(\mathrm{t}) \tag{2}$$

$$\overline{S(\mathrm{t})} = \sum \frac{1}{T} S_k(\mathrm{t}) \tag{3}$$

$$\min \frac{1}{T} \sum_{t=1}^{T} \left(S(\mathrm{t}) - \overline{S(\mathrm{t})}\right)^2 \tag{4}$$

3.2 Constraint Condition

(1) **Heating equipment**

In this paper, the conversion efficiency of two types of thermoelectric energy is described by the performance coefficient COP. H_t^{rb} indicates the heat production power of the heat pump during the t period, P_t^{rb} indicates the power consumption of the heat pump during the t period, and the heat production power should meet the upper and lower limits of the power. The relationship is as follows (Fig. 2):

$$COP = \frac{H_t^{rb}}{P^{rb}} \tag{5}$$

$$0 \le H_t^{rb} \le H_t^{rb,\max} \tag{6}$$

As an auxiliary heat source of the system, the electric boiler can supply heat for air conditioners, electric water heaters, etc. (such as peaking heat source), and generate electricity through the electric energy provided by the power grid. Electrothermal conversion efficiency COP_{dgl},

$$COP_{dgl} = \frac{H_t^{dgl}}{P_t^{dgl}} \tag{7}$$

$$0 \le H_t^{dgl} \le H_t^{dgl,\max} \tag{8}$$

(2) **Heat equipment**

In this section, air-conditioning is used as an example to model the heat-consuming equipment. C is the equivalent heat capacity of the air conditioner, which means the heat that needs to be absorbed or released every time the temperature in the air-conditioned room changes by one degree, and η means the energy-efficient ratio

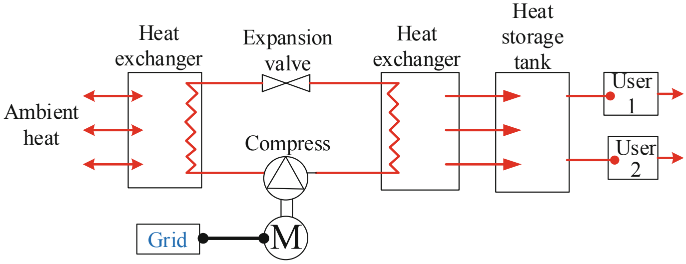

Fig. 2 Heat pump model

of heating (colding), E_{air} indicates the equivalent power consumption, the relationship is as follows

$$E_{\text{air}} = \frac{C|T_1 - T_2|}{\eta} \tag{9}$$

In the formula, T_1 represents the indoor initial temperature, and T_2 represents the temperature after the indoor air conditioner is adjusted.

(3) **Heat storage equipment**

The heat storage device is mainly used to stabilize the thermal energy load fluctuation and store excess heat energy. $d_k(t)$ is the residual heat of the energy storage device at time t, which should be less than the upper limit of energy storage of the energy storage device $d_k^{\max}$; $e_k^s(t)$ is the amount of energy storage state change during this period, As shown in the formula:

$$0 < d_k(t) < d_k^{\max} \tag{10}$$

$$d_k(t) = d_k(t-1) + e_k^s(t) \tag{11}$$

$$e_k^s(t) = \begin{cases} I_k^S(t) * \mu_s & (I_k^S(t) \geq 0) \\ I_k^S(t)/\mu_s, & (I_k^S(t) < 0) \end{cases} \tag{12}$$

(4) **Power load**

The basic load I_k^B is the basic power used to ensure the normal daily life of the user. It is fixed and can be used to obtain daily forecast data according to historical power consumption data, as shown in the formula.

$$I_k^B = I_k^{\min} \tag{13}$$

The schedulable power load I_k^A is the power consumption part that satisfies the user's high quality of life. Under the guarantee of high quality living conditions, the total load that can be scheduled for power consumption should meet the constraint condition s_k^A, and considering the factors such as power protection, it should meet the constraint conditions. $I_k^{\max}$, as shown in Formula (15):

$$\sum I_k^A = s_k^A \tag{14}$$

$$0 \leq I_k^A \leq I_k^{\max} \tag{15}$$

4 Solution of Demand Response Strategy

4.1 Basic Idea

The whole process of user k participating in DR is divided into grid side operation and user side operation, which can be divided into four steps,

Step 1: collect the user's electricity information. The user's electricity information will be collected in 24 h time periods throughout the day, including the electricity consumption per unit period and the electricity consumption behavior of household appliances.

Step 2: the user's heat load furniture is collected. After the information in step 1 is included, the power, quantity, duration of use, power consumption per machine and relative heat production of household appliances are also counted.

Step 3: according to the initial optimization goal of the power grid side, the hybrid particle swarm optimization algorithm is used to find the thermoelectric ratio range within the optimization goal, that is, to determine the optimal load scheduling interval, determine the initial thermoelectric ratio and send the DR contract to the user.

Step 4: users make judgment according to their degree of adjustment and satisfaction. If you agree, the scheduling policy is completed; if you disagree, go back to 3.

4.2 Solving Process

The optimization process of objective function in this paper is a typical nonlinear programming problem. At present, such optimization process can use convex optimization method, intelligent algorithm and some intelligent algorithm integration software, etc., in which the intelligent algorithm particle swarm is simple and easy to realize and does not need to adjust many parameters. In the process of object optimization, particle swarm optimization algorithm is selected in this paper (Fig. 3).

Compared with the traditional convex optimization method, the traditional particle swarm optimization algorithm has the advantage of faster convergence and easier implementation. Residents' daily load classification and their participation in optimization load classification are shown in Fig. 4. As described in Sect. 2.2, when the total load remains unchanged, the method in this paper increases the total amount of dispatchable load and improves the accuracy of the results.

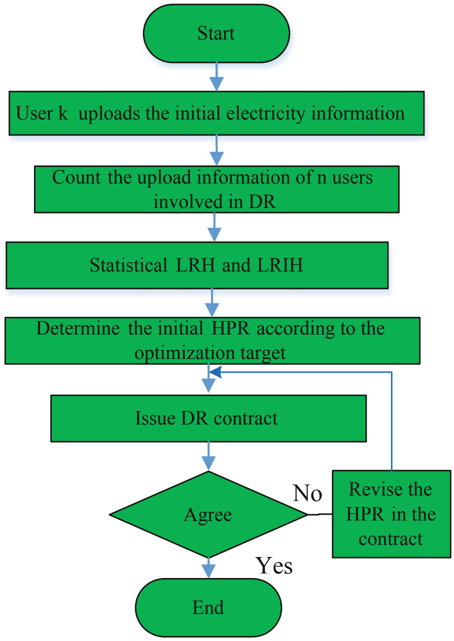

Fig. 3 Strategy solving diagram

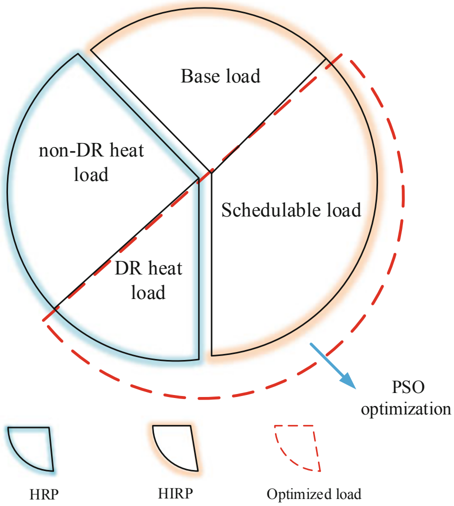

Fig. 4 PSO solving model solves the figure

5 Experimental

5.1 Parameter Settings

In this section, according to the previous section, the thermal park energy-saving intelligent park energy model design simulation experiment, the main parameters of the experiment: (1) For the basic user data parameter part, the user basic load data is from [9], drawing on the US Renewable Energy Office (Office of Energy Efficiency & Renewable Energy, EERE) provides commercial and residential daily electricity data sets to build users' predicted load; (2) User's schedulable load parameter setting reference [9]. The setting results are shown in Table 2. (3) The capacity of the energy storage device is 10 kW h, the initial stored energy stored is 0, the storage efficiency is 90%, and the upper limit power of the energy storage device is 3 kW. (4) The heat pump capacity is 3 kW, the coefficient of performance COP is 3.5, the upper limit of the electric boiler is 1 kW, and the coefficient of performance is 0.5.

The relevant parameters of particle swarm optimization algorithm are set as follows: population size N is 100; The acceleration coefficient c_1 and c_2 are 1.49445. The number of iterations is 200; Maximum speed 0.5; The inertia weight is 0.9. The comparison algorithm selected in this paper is centralized scheduling algorithm (Table 2).

5.2 Comparison of Total Load of Different HPR

First, when the thermoelectric ratio changes from 10 to 100%, the total user load of the demand response strategy considering the thermoelectric linkage is compared with the centralized scheduling strategy and the total load of the disordered power consumption method without the demand response strategy. The abscissa is time (h) and the range is 1–24; the ordinate indicates the total load (kW) (Fig. 5).

It can be seen from the figure that (1) The load curve corresponding to different HPR is different. This is because the thermoelectric ratio is different and the user's schedulable load is different. (2) When the demand response strategy of thermo-electric linkage is compared with the centralized scheduling strategy, the load curve

Table 2 User home appliances parameters

Type	Average number	Transitivity	Rated power (kW)
Dish-washer	0.7	No	600
Air condition	1.5	Yes	1000
Washing machine	1	No	500
Water heater	1	Yes	1500
Refrigerator	1.2	Yes	200

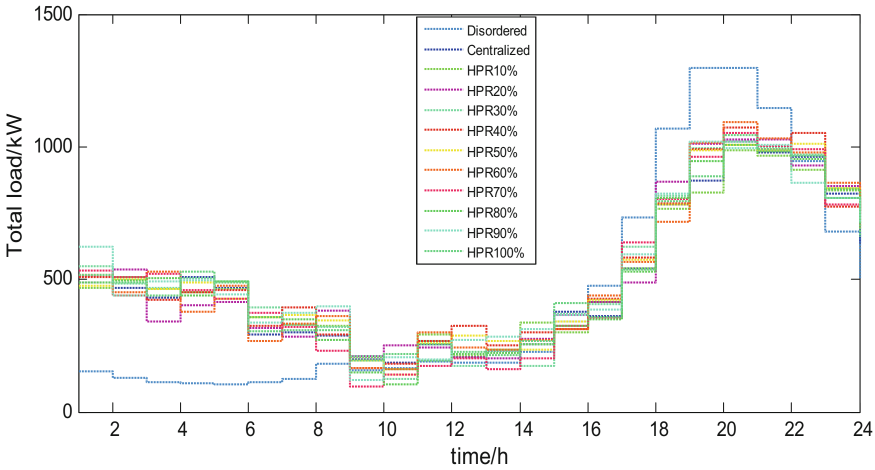

Fig. 5 Curve: total load of different HPR

changes in a variable load flexible range when the thermoelectric ratio is different, and there is a possibility that one load curve is better than the centralized scheduling load curve. The values of the indicators are as follows Table 3.

In the standard variance comparison: the reduction ratio of this method is 44.5–55.6%, and the reduction ratio of centralized scheduling is 50.4%, which greatly reduces the standard deviation and reduces the load volatility; the peak-to-valley difference has similar conclusions.

The comparison of standard deviation and peak-to-valley difference in different proportions is as follows, where the horizontal axis represents the thermoelectric ratio (%) The left vertical axis is the standard deviation (kW), and the right vertical axis is the peak-to-valley difference (kW) (Fig. 6).

Table 3 Demand response performance comparison

Method	Peak value	Standard variance	Peak-valley difference
Disordered	1298	414.7	1193
HPR 10%	1119	231	823.2
HPR 20%	1019	216.2	744.3
HPR 30%	896.7	187	587.2
HPR 40%	975.5	187.7	640.7
HPR 50%	851.8	184.4	597.3
HPR 60%	969.6	202.4	636
HPR 70%	876.9	199.3	638.7
HPR 80%	959.8	217.4	698.1
HPR 90%	992.4	231.1	766.6
HPR 100%	968.7	227.4	769.5
Centralized	909.7	205.6	636.7

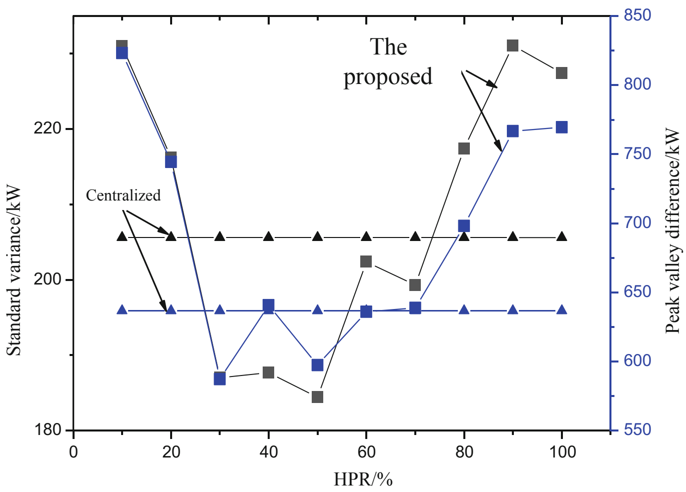

Fig. 6 Curve: demand response performance comparison

It can be seen from the figure that (1) when the thermoelectric ratio changes from 30 to 70%, the standard deviation of the method is lower than the centralized scheduling method; when the thermoelectric ratio changes from 30 to 70%, the peaks and valleys of the method The difference is close to or lower than the centralized scheduling method. It shows that the method is better than the centralized scheduling method when the thermoelectric ratio is from 30 to 70%. (2) As shown in Fig. 7, the blue area in the figure is the optimal load curve interval obtained by the method in this paper.

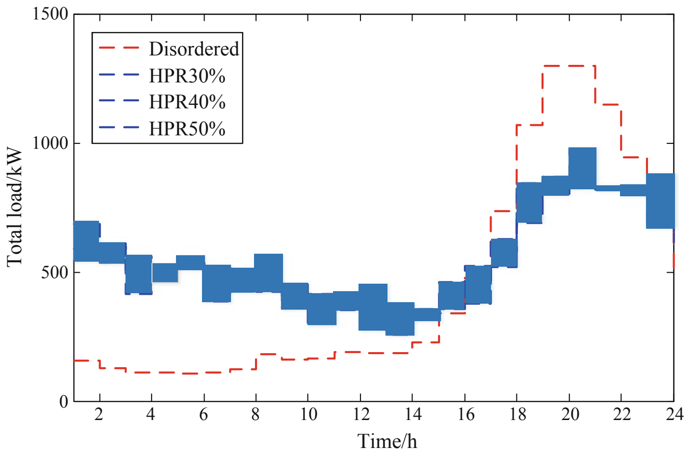

Fig. 7 Curve: optimal scheduling load interval

6 Conclusion

This paper proposes a cogeneration demand response strategy considering the thermal energy access at the source end and the cogeneration of the heat at the end of the load. The energy consumption of the smart park is analyzed and coordinated and coordinated. The heat load ratio of the participating linkages is changed. The superiority of the strategy and the optimal demand response load interval scheduling results.

Acknowledgements This work is funded by China State Grid Hunan Electric Power Co., Ltd. Science and Technology Project (Research on Control Strategy of Precision Load Shedding System of Hunan Power Grid).

References

1. Zhang X, Li J, Fu H (2016) Global energy interconnection dialogue industry 4.0. Power Grid Technol 40(06):1607–1611
2. Liu S, Zhang D, Zhu C, Li W, Lu W, Zhang M (2016) A view on big data in energy internet. Autom Electr Power Syst 40(08):14–21 + 56
3. Sun H, Guo Q, Wu W, Wang B (2019) Multi-energy integrated energy management system for energy internet: design and application. Autom Electr Power Syst 10(05):1–8
4. Cheng H, Hu W, Wang L, Liu Y, Yu Q (2019) Review on research of regional integrated energy system planning. Autom Electr Power Syst 43(07):2–13
5. Zhou X, Chen S, Lu Z, Huang Y, Ma S, Zhao Q (2018) Technology features of the new generation power system in China. Chin J Electr Eng 38(07):1893–1904 + 2205
6. Shao S, Dai S, Hu L, Ding Q, Xie H (2008) Research on heat-electricity combined scheduling method considering the characteristics of the heating network. Power Syst Prot Control 46 (10):24–30
7. Lu Z, Yang Y, Geng L, Pan L, He L, Li X (2018) Low-carbon economic dispatch of the integrated electrical and heating systems based on benders decomposition. Chin J Electr Eng 38 (07):1922–1934 + 2208
8. Shi J, Huang W, Tai N, Fan F, Yu M, Ma Z (2008) A strategy to suppress fluctuation of distributed renewable energy in microgrids with heat-power linkage system. Chin J Electr Eng 38(02):537–546 + 684
9. Lu J, Chen Z, Gong G, Xu Z, Pei B (2019) Classification and analysis method of residential electricity consumption based on extreme learning machine. Autom Electr Power Syst 43 (02):97–104