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Research on residential load optimization model based on the adaptive harmony search-particle swarm optimization algorithm

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Abstract. In the research of energy internet, demand response has become a hot issue which has been widely concerned. The residential load optimization model was constructed, which takes into account factors such as environmental change, electricity price, user habits, load fluctuation and so on. The adaptive harmony search-particle swarm optimization algorithm was used to solve the model, which got the program to meet the needs of users. It is the fusion of the particle swarm optimization algorithm and the harmony search algorithm. The simulation results were based on the actual time-sharing price, outdoor temperature and load parameters. After the simulation, the user load curve was improved and the electricity consumption and energy used was obviously reduced, which proved the algorithm is effective.

1. Introduction

Demand response has become a hot issue in the research of energy internet. Smart home management system (SHMS) as a necessary means to achieve demand response has become the focus of research. An intelligent household appliances management system is proposed in [1], which designs a scheme that users participate in demand response and save electricity cost under the background of time-of-use electricity price, but does not consider the impact of external environment changes on temperature-controlled load model. A load optimization model of household user-side microgrid considering time-of-use price and demand response is established and solved by particle swarm optimization algorithm in [2], which achieves the reduction of power purchase cost and the demand response of controllable load. However, it is difficult to effectively satisfy the user's comfort. Literature [3] proposes an immune optimization algorithm based on dynamic antibody memory library for automatic demand response in smart home, but it only considers the impact of load operation time on user comfort, and does not analyse the actual effect of load operation in depth.



In this paper, the residential load optimization model is constructed, and the adaptive harmony search-particle swarm optimization algorithm is used to solve the model. This can obtain the home load optimization scheme that meets the use's requirements.

2. Residential load optimization model

Assume the optimization time set by users is H hours, the model divides each hour into l time periods, and the optimization time is $L=l \cdot h$ time periods. There are n loads in the SHMS. The objective function of minimum electricity consumption cost can be expressed by formula (1). The total load power constraints and rated load power constraints can be expressed by formulas (2) and (3), respectively.

$$\min C = \sum_{a=1}^n \sum_{t=1}^L e_{a,t} \cdot p(t) \quad (1)$$

$$\sum_{a=1}^n e_{a,t} \leq E_{\max} \quad (2)$$

$$e_{a,t} = e_{a,normal} \text{ 或 } e_{a,t} = 0 \quad (3)$$

Where C is the total electricity consumption cost; E_{\max} is the upper limit of total electricity consumption; $p(t)$ is the electricity price at t period; $e_{a,t}$ is the electricity quantity for the a th load at t period; $e_{a,normal}$ is the rated electricity quantity for the a th load.

2.1 Air Conditioner

The operating power of the air conditioning model in this study is rated power. Generally, the change of indoor temperature is related to the structure of house, building materials, the initial value of room temperature, outdoor temperature, heating or cooling performance of air conditioning. So the room temperature model is established:

$$T_{in}(t) = T_{in}(t-1) + \alpha[T_{out}(t) - T_{in}(t-1)] + \beta \cdot e_{1,t} \quad (4)$$

$$T_{low} \leq T_{in}(t) \leq T_{high} \quad (5)$$

Where $T_{in}(t)$ 、 $T_{out}(t)$ is the indoor and outdoor temperatures in t period; α is the influence coefficient of outdoor temperature on room temperature; β is the influencing coefficient of electricity consumption on room temperature in unit time of air conditioning operation. T_{high} 、 T_{low} is the upper and lower limits of room temperature setting by users. The method of parameter determination is detailed in reference [4].

2.2 Water Heater

As a temperature-controlled load, the characteristics of water heater are similar to air conditioning. Generally, the room temperature is lower than the water temperature inside the water heater, so the water temperature will gradually decrease with the passage of time. For simplicity, this study assumes that the temperature of water cooling is proportional to the time. The change of hot water temperature is affected by the heat insulation performance, heating performance and initial water

temperature of the water heater. Considering the factors mentioned above, the water temperature model can be summarized as follows:

$$T_{water}(t) = T_{water}(t-1) - T_{cooling} + \gamma \cdot e_{2,t} \quad (6)$$

$$T_{water,l} \leq T_{water}(t) \leq T_{water,h} \quad (7)$$

Where $T_{water}(t)$ is the water temperatures in t period; $T_{cooling}$ is the temperature of water cooling in each period; γ is the influencing coefficient of electricity consumption on water temperature in unit period of water heater. $T_{water,h}$, $T_{water,l}$ is the upper and lower limits of water temperature setting by users. The method of parameter determination is detailed in reference [5].

2.3 Electric Vehicle

Customer comfort of electric vehicles is mainly reflected in whether the state of charge (SOC) of electric vehicles reaches the lower limit of SOC set by users after the optimal period of planning. Under the condition that the user sets SOC to reach at least 80% of the rated battery capacity after charging, the charging model of electric vehicle in this study is as follows:

$$0.8E_{3,full} \leq \sum_{t=1}^L e_{3,t} + E_{3,start} \leq E_{3,full} \quad (8)$$

Where $E_{3,full}$ is the rated capacity of batteries for electric vehicles; $E_{3,start}$ is the initial capacity of batteries for electric vehicles.

2.4 Washing Machine

The washing machine is a transferable load. The washing machine needs to run continuously until the task is completed. The washing machine runs at constant power during operation period. When the washing machine needs to run for four consecutive periods to complete the task, the operational model is described as:

$$\sum_{t=t_s}^{t_s+3} e_{4,t} = \sum_{t=1}^L e_{4,t} = E_{4,normal} \quad (9)$$

$$1 \leq t_s \leq L-3 \quad (10)$$

Where $E_{4,normal}$ is the rated electricity quantity for washing machine to complete tasks; t_s is the operation period of washing machine.

3. Adaptive harmony search-particle swarm optimization algorithm

Particle swarm optimization algorithm has shown its superiority in many optimization problems because of its simple principle, strong versatility and good convergence stability [6]. However, particle swarm optimization algorithm has a single search direction and is easy to fall into local optimum, which makes the algorithm converge ahead of time. Harmony search algorithm is a new intelligent optimization algorithm. It has simple concept, fewer parameters, faster convergence speed and easy to jump out of local optimum, but its search direction is random and its convergence stability is poor. This paper combines the advantages of the two algorithms and adopts the fusion

algorithm of particle swarm optimization and harmony search optimization to optimize the solution. Firstly, it iterates the initial solution in harmony memory database for a certain number of times by taking advantage of the strong directivity and good stability of particle swarm optimization algorithm, so that it can quickly approach the optimal solution. Then it further searches for the optimal solution by using various update mechanisms of harmony search algorithm. The specific steps of the algorithm are as follows:

(1) The basic parameters of the algorithm are determined, including harmony memory size M , retention probability $P1$, tone regulation probability $P2$, tone disturbance bandwidth bw , acceleration constants $c1$ and $c2$, inertia weight w , iteration number N , etc.

(2) A harmony memory library containing M random solutions is generated, which is regarded as the initial population. Particle swarm optimization algorithm is used to iterate for a certain number of times, and the individual optimal solution of each particle generated in the iteration process is taken as the initial solution of the new harmony memory library. Particles are updated according to the following formula:

$$v_i^{k+1} = \omega v_i^k + c_1 \mu (P_i - x_i^k) + c_2 \eta (P_g - x_i^k) \quad (11)$$

$$x_i^{k+1} = x_i^k + v_i^k \quad (12)$$

Where μ and η are the random numbers between 0 and 1. P_i and P_g are the individual optimal position and the global optimal position.

(3) Each iteration produces the components of the new solution in the following way. Firstly, a random number $r1$ between 0 and 1 is generated. If $r1$ is less than $P1$, a solution component is selected within HM, other the value is selected randomly in the feasible region of the external variable of HM. If the solution component is obtained in HM, it is regenerated into a random number $R2$ between 0 and 1. If $R2$ is less than $P2$, the solution component is disturbed. The specific perturbation formula is as follows:

$$x_i^{new} = x_i^{new'} + bw(2rand - 1) \quad (13)$$

Where $x_i^{new'}$ and x_i^{new} are the new solution components before and after disturbance respectively. $rand$ is the random numbers between 0 and 1.

(4) If the objective function value of the new solution is better than that of the worst solution in harmony memory, the worst solution is replaced by the new solution, and a new harmony memory library with the size of M is obtained.

(5) Check whether the maximum number of iterations is reached, and if so, the optimal solution in the output harmony memory is solved by the problem, otherwise repeat steps (3) and (4).

4. Example analysis

4.1 Example Parameter

This example divides every hour into four periods, and optimizes 24 hours (96 periods) starting from 6:00 a.m. The price information of the example can be found in reference [7]. Load parameters and user settings are shown in Table 1. The condition of basic load is shown in Figure 1. Time-of-use (TOU) tariffs have three kinds of tariffs: peak time, peace time and valley time, which

are also used as a signal of demand response. The outdoor temperature curve of this example is shown in Figure 2.

Table 1. Load parameters and user settings

Load	Power /kw	Initial temperature /°C	Initial electricity consumption /kwh	Battery capacity /kwh	User setting requirements
Lighting and entertainment	0.2-0.4	/	/	/	Self control
Air conditioner	1.6	25	/	/	23°C-26°C
Water Heater	3	42	/	/	42°C-50°C
Electric Vehicle	3	/	20	40	Battery capacity reaches 80%
Washing Machine	0.4	/	/	/	Continuous operation

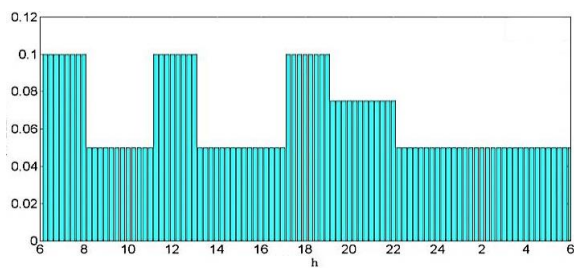


Figure 1. The condition of basic load

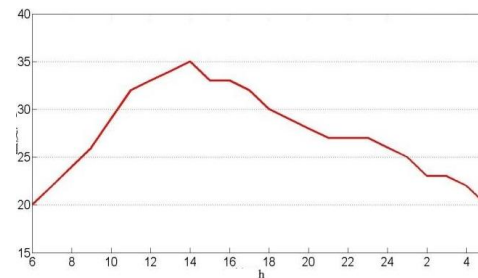


Figure 2. Outdoor temperature

4.2 Analysis of Simulation Results

The total load operation before and after optimization is shown in Figure 3 and Figure 4. Before optimization, the total load is mostly concentrated in the period of noon and evening, which is at the peak of electricity consumption, and the electricity price is high, which is contrary to the demand side response advocated by the power grid. In addition, users use electricity according to their living habits. The predictability and speed of their control are not strong, which can easily lead to untimely operation control and waste of power. After optimization, the total load is generally reduced and reasonably distributed. This evades the peak electricity price and transfers the load to the low electricity price periods such as morning and night, thus forming the demand side response and achieving the goal of peak cutting and valley filling.

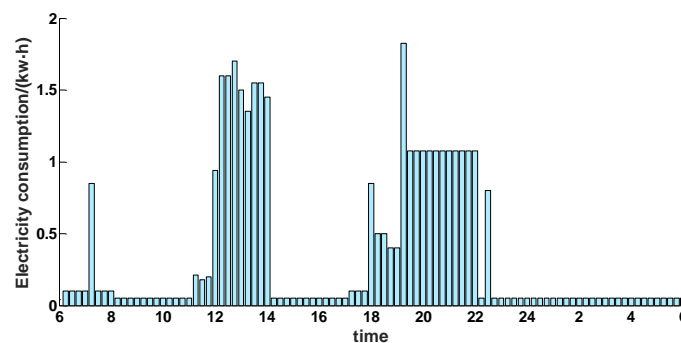


Figure 3. Total load before optimization

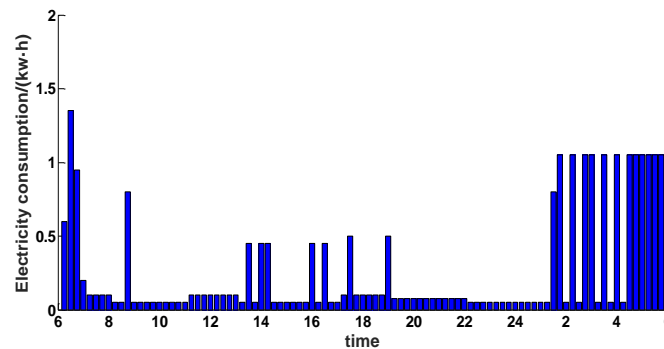


Figure 4. Total load after optimization

Table 2. Results comparison before and after optimization

Index	Before optimization	After optimization(PSO)	After optimization (algorithm proposed in this paper)
Electricity Consumption/kwh	36.34	25.30	24.05
Electricity Cost/yuan	39.37	15.02	14.12

From Table 2, it can be seen that the total power consumption is 36.34 kwh, and the total cost is 39.37 yuan before optimization. After optimization by particle swarm optimization algorithm, the power consumption is 25.3 kwh, and the cost of electricity consumption is 15.02 yuan. It reduces the electricity consumption by 30.4% and saves about 61.8% of the electricity consumption. After optimization by the adaptive harmony search-particle swarm optimization algorithm, the power consumption is 24.05 kwh, and the cost of electricity consumption is 14.12 yuan. It reduces the electricity consumption by 33.8% and saves about 64.1% of the electricity consumption. The energy saving and cost saving effect of the scheme is obvious.

5. Conclusion

The residential load optimization model was constructed, which met the demand response strategy for power grid and the user's requirement to save the electricity cost. The adaptive harmony search-particle swarm optimization algorithm was used to solve the model. The simulation results show that it achieves the goal of peak cutting and valley filling.

6. References

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Acknowledgments

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