Study on the strategy of adjustable potential of residential power load

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Abstract. With the rapid development of power grid technology in China, the residential power load, as one of the most important load, is gradually penetrated by demand response. In this paper, residential users in low-voltage area are taken as the research object. Based on the classification of demand-side power load and the optimization objective of minimizing the comprehensive cost of residential users, a real-time demand response scheduling strategy is proposed, which is suitable for load aggregation and improves the participation of residential users. Under the condition that the user satisfaction is not affected as far as possible, the power consumption habit of the user is positively affected, and the expected load reduction target is achieved at the same time. The comprehensive power consumption cost of the user is effectively reduced, and the purpose of energy saving and peak and valley filling is achieved, so as to achieve the orderly power consumption of household energy.

1. Introduction
Domestic demand side management adopts an orderly power consumption mode with administrative guidance as the main and economic means as the auxiliary. The potential for demand response resources of power users has not been fully digging. Residential users have numerous household appliance flexible load resources and scattered distribution, with large decentralized response behavior and uncertainty, which makes it difficult to be directly scheduled by the power grid [1].

Adjusting the electricity consumption behavior of residents is important content and effective way for the intelligent construction of smart power grid, which can not only improve the electricity consumption efficiency of residents, but also improve the operation efficiency of the power grid, so as to realize intelligent demand response between residents and smart power grid [2]. The indirect resource scheduling can be achieved through price-based demand response strategies and incentive-based demand response strategies. It provides various forms of auxiliary services (frequency control, voltage control, standby, etc.), participates in demand response projects, increases or decreases output by bidding in the balanced market, and alleviates transmission and distribution congestion, etc. [3], realizes the optimal allocation of resources, and has good social and economic benefits.

2. Control mechanism
Load aggregators must study different types of loads and their demand response potentials [4]. While collecting electricity price signals for the current time period from the grid side, they should collect and record the operation status, characteristics and power consumption data information of other load equipment for each user's load at each time period every day through smart meters one month in advance.
After receiving the previous power consumption data provided by the load aggregator and the suggested power consumption for the user (the suggested power consumption is the result of comprehensive consideration of the load aggregator on the user's electricity consumption cost, comfort level and adjustment speed so as to minimize the user's own cost) and the grid-side electricity price information, the user submits the expected load value in this demand response period to the load aggregator as its expected electricity consumption in combination with his own electricity consumption habits.

The load aggregator shall reduce its expected power consumption according to the established user queue order until the load reduction target is met. In addition, various forms of compensation, such as additional compensation or electricity discount, shall be made to the users who reduce the load [5]. If the actual power consumption on the customer side is more than the reduced power consumption, the electricity consumption will be purchased at the higher electricity price. If the actual electricity consumption on the customer side is less than the reduced power consumption, the electricity consumption will be sold at the lower price of the first step (the first step can be priced appropriately according to the actual situation). The commercial real-time demand response model of load aggregation is optimized to realize the real-time demand response scheduling of each period of flexible load.

3. Model establishment

3.1 Load model

From the perspective of the independent response characteristics of residential users, household loads can be divided into three categories according to the user's electricity habits and the power settings of each appliance:

Considering the influence of electricity price and adjustment speed of load aggregator on load, the mathematical model of power load can be expressed as follows:

$$P = P_0 + f_{dj}(P_{dj}, \mu_1) + f_{tj}(P_{tj}, \mu_2)$$  \hspace{1cm} (1)

Where: $P$ represents the response load after a large number of influencing factors are applied; $P_0$ represents conventional load regardless of any influencing factors; $f_{dj}$ and $f_{tj}$ respectively represent the response functions of electricity price and regulation speed to power load; $P_{dj}$ and $P_{tj}$ respectively represent the load after taking into account the electricity price response and adjustment speed. $\mu_1$ and $\mu_2$ are the electricity price and the regulation speed of load respectively.

3.2 Objective function

According to the user's electricity consumption habits, real-time electricity price information and the suggestions of load aggregator, users can draw up electricity consumption plans. Generally, the expected load value of users will minimize the comprehensive cost during the demand response period.

- The comprehensive cost of users consists of electricity consumption cost and discomfort cost:

$$C_{zh} = C_{yd} + C_{bss}$$  \hspace{1cm} (2)

Where: $C_{zh}$ is the comprehensive cost of users, $C_{yd}$ is the cost of electricity consumption and $C_{bss}$ is the cost of discomfort.

- The cost of electricity consumption:

$$C_{yd} = Ep\Delta t_1 + \Delta E_1 \Delta p_1 \Delta t_2 - \Delta E_2 \Delta p_2 \Delta t_2$$  \hspace{1cm} (3)
Where:  \( E \) is the electricity price of this period, \( P \) is the load of the period, and \( \Delta t \) is the duration of the demand response period. \( \Delta E_1 \) and \( \Delta E_2 \) are the price of partial power consumption purchased and sold by users respectively. \( \Delta p_1 \) and \( \Delta p_2 \) are the partial power consumption purchased and sold by users respectively. \( \Delta t_2 \) is the demand response time of this period.

- The cost of discomfort:

\[
C_{bx} = \omega \left( T_{sd} - T_{j} \right)^2 \Delta t_1 + \gamma \Delta t_3
\]

(4)

Where: \( \omega \) is the sensitivity coefficient of the user to temperature, \( T_{sd} \) is the set temperature for the air conditioner, and \( T_{j} \) is the best somatosensory temperature for the user. \( \gamma \) is the dispatch sensitivity coefficient. \( \Delta t_3 \) is the length of dispatch time for load aggregators to buy or sell residential loads.

- The comprehensive cost of users is obtained as follows:

\[
C_{zh} = E \Delta t_1 + \Delta E_1 \Delta p_1 \Delta t_2 - \Delta E_2 \Delta p_2 \Delta t_2 + \omega \left( T_{sd} - T_{j} \right)^2 \Delta t_1 + \gamma \Delta t_3
\]

(5)

3.3 Constraints

In this paper, the transferable load and the reducible load are taken as the main research objects to study the residential user load. Therefore, in addition to the conventional constraints of power system equipment and power grid, the transferable load and the reducible load are regulated as follows:

- transferable load

If the user sets the initial running time as \( t_a \) and the user's acceptable transfer period interval as \( t_c \), the constraint shall be met:

\[
t_a \leq t_c \leq t_h
\]

(6)

- the load can be reduced

Make the following upper and lower limit constraints on the load can be reduced of residential users:

\[
p_{cut, min} \leq p_{cut} \leq p_{cut, max}
\]

(7)

Where: \( p_{min} \) and \( p_{max} \) are the upper and lower limits of the load can be reduced.

4. Algorithm

Intelligent algorithm Particle Swarm Optimization (PSO) has good effect in solving optimization problems because of its simplicity and easy implementation. Considering the uncertainty of scheduling, user behavior and other constraints, the adaptive direction of particles will also be uncertain. Therefore, an improved particle swarm optimization algorithm is established. Therefore, in the process of forming particle swarm and solving the optimal problem, the improved particle swarm optimization algorithm judge the state of particles at any time, discard the particles that do not meet the constraints and regenerate the particles. The updating formula of particle position and velocity is as follows:

\[
v_{i}^{k+1} = \omega \cdot v_{i}^{k} + c_1 \cdot rand \cdot \left( p_{best}^{k} - x_{i}^{k} \right) + c_2 \cdot rand \cdot \left( g_{best}^{k} - x_{i}^{k} \right)
\]

(8)

\[
x_{i}^{k+1} = x_{i}^{k} + v_{i}^{k+1}
\]

(9)
Where: $v_i^k$ indicates the velocity of particles in the Kth iteration; $x_i^k$ indicates the current position of the particle in the Kth iteration; $p_{best_i}^k$ is the position of the individual extreme point of the particle; $g_{best}^k$ is the position of the global extreme point of the whole population. $c_1$, $c_2$ are learning factors; $rand$ is a random number between [0,1]; $\omega$ is inertia weight, which can accelerate convergence and is not easy to fall into local optimum. The algorithm flow is as follows:

![Flow chart of improved Particle Swarm Optimization](image)

Figure 1. Flow chart of improved Particle Swarm Optimization

5. **Simulation and analysis**

5.1 **Case study**

The simulation scenario is set as a demand response plan participated by a community in Jilin. The simulation takes about 300 residents in the community as an example. The user load data is the historical data of the previous 30 days, including daily load opening time and running time. It is assumed that the load parameters of the same kind in the community are the same. If the actual electricity consumption on the customer side is more than the reduced electricity consumption, the electricity consumption will be purchased at the higher electricity price of Jilin. If the actual electricity consumption on the user side is less than the reduced electricity consumption, the electricity will be sold at the lower price of the first step price (the lower price of the first step price is 0.5 yuan/degree according to the current electricity price plan of Jilin).
6. Conclusion
This paper proposes a demand response strategy that takes into account consumer psychology, user satisfaction and the adjustment speed of load aggregators. This scheduling strategy can enable residents to give full play to their power consumption autonomy when considering their own power consumption habits and step tariff incentives, and effectively reduce the comprehensive power consumption cost of users. At the same time, for the power grid side, the frequency fluctuation phenomenon and the pressure of expansion capacity investment are also effectively relieved. Therefore, the implementation of the demand response strategy has certain economy for both the user side and the power grid side, which can provide certain help for the residents' load participation in the demand response decision-making.

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