Research on Multi-target Equipment Group Optimal Control Strategy for Smart Energy Gateway for Large Electric Customer

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Abstract. At present, the electric load in China is increasing rapidly. The peak-to-valley gap of the power grid is continuously increasing, which has brought a lot of economic and security issues. Traditional solutions usually start from the power supply side, with large cost and poor effect. With the deepening of electric technology research, electric power demand side management has attract more and more attention, and large electric customers have become the first choice of state grid companies due to their large power loads and high willingness to participate. In order to cooperate with large electric customers’ participation in demand-side response, this paper builds an equipment group optimization model to meet the requirements of the load reduction instructions while taking users’ comfort and equipment participation into account. Finally, simulation verify the practicability of the proposed strategy.

1. Introduction

The peak pressure of power grids has increased year by year, and new challenges have been faced in power supply and demand balance. In order to solve the above problems better, electric demand side management is proposed. The United States first introduced the concept of demand side management in 1984\textsuperscript{[1]}. Currently, demand-side management centers have been established in many provinces and cities, especially in Guangdong and Jiangsu. The development of demand response projects has a positive effect on improving the economic and safe operation of power systems\textsuperscript{[2-4]}. There are many incentives to stimulate user demand response, such as Real Time Pricing (RTP), Time of Use (TOU), Critical Peak Pricing (CPP), Interruptible Load (IL) and Demand Side Bidding (DSB). Among them, the interruptible load has become a common method for large electric customers to participate in demand response due to its strong operability. Reference [5-6] used the interruptible load in the secondary backup auxiliary service market. The user signed an interruptible load contract with the Independent System Operator (ISO), which was interrupted during the peak period of power consumption or the shortage of resources. Reference [7] used the scene analysis method to model the dispatching model of power system with interruptible load. Reference [8] used opportunity constraint programming to comprehensively consider random factors such as unit failure, line failure, load prediction error, and interruptible load default. Taking the minimum system operating cost as the objective function to construct an optimization model with interruptible load. Tuan systematically researches interruptible
load management in Sweden. Majumdar et al. formed an optimal power flow framework to inform users in advance. In order to improve the response quality and complete the automatic response, this paper proposes a load control strategy suitable for demand response. A numerical example is used to verify the strategy, and the strategy can be used to cut the peaks.

2. Multi-target equipment group optimal control strategy

2.1. Regulatory model

The smart energy gateway for large electric customer adjusts the equipment connected to it by control strategy according to the load reduction instructions issued by the power supply and demand interactive service platform. Comfort can be characterized by the amount of load reduction. Less reduction indicates higher comfort. The objective function are as follows:

\[ Z_i = \lambda_1 (N+n) + \lambda_2 (\Delta p_a + \Delta p_L) \]  
\[ \Delta p_a = \Delta p_{a1} + \ldots + \Delta p_{aN} \]  
\[ \Delta p_L = \Delta p_{l1} + \ldots + \Delta p_{ln} \]

Where \( \Delta p_a \) is the total load that can be reduced by air conditioner; \( \Delta p_{aN} \) is the load that can be reduced by air conditioner number N; N is less than the total number of operational air conditioner; \( \Delta p_L \) is the total load that can be reduced by illumination; \( \Delta p_{Ln} \) is the load that can be reduced by illumination number n; n is less than the total number of operational illumination; \( \lambda_1, \lambda_2 \) is the weight coefficient which selected by the customers.

Constraints are as follows:

\[ \Delta p_a + \Delta p_L \geq \Delta P \]  
\[ \Delta P = \Delta P_i + \Delta P_{air} + \Delta P_w + \Delta P_f \]

1) Increase global temperature

Based on room temperature at 26 °C, the air-conditioner energy consumption is reduced by about 7% when air-conditioner set temperature increase 1 °C.

\[ \Delta P_i = 7\% \times P_{air} \times \Delta T \]

Where \( \Delta P_i \) is the load that can be reduced by the air conditioner, kW; \( P_{air} \) is the power of air conditioner system, kW; \( \Delta T \) is the value of temperature adjustment, °C.

2) Increase chilled water temperature

The air-conditioner energy consumption is reduced by 0.91%-1.97% when chilled water temperature increase 1 °C.

\[ \Delta P_w = \Delta T' \times \delta_2 \times P_{\text{chilled}} \]

Where \( \Delta P_w \) is the load that can be reduced by the air conditioner, kW; \( \Delta T' \) is the increase temperature of water, °C; \( \delta_2 \) is the correction value which range is 0.91%-1.97%.

3) Chilled water flow

The air-conditioner energy consumption is reduced when chilled water temperature chilled water flow is reduced.

\[ \Delta P_v = (V_o / V_r) \times \delta_3 \times P_{\text{chilled}} \]

Where \( \Delta P_v \) is the load that can be reduced by the air conditioner, kW; \( V_o \) is regulate total water flow; \( V_r \) is total running water flow; \( \delta_3 \) is correction value which range is 20%-80%. 
4) Fan frequency conversion control

\[
\Delta P_f = \sum (1 - (f_i / f)^3) \cdot P_b + \delta \cdot P_m
\]  \hspace{1cm} (9)

Where \( \Delta P_f \) is the load that can be reduced by the air conditioner, kW; \( f_i \) is limited frequency after fan frequency conversion, Hz; \( f_i \) is reference frequency; \( P_b \) is fan reference load, kW; \( \delta \) is correction value which is 5%.

(2) Illumination

\[
\Delta P_{I_n} = \begin{cases} 
0, & \text{turn on} \\
P_s, & \text{turn off}
\end{cases}
\]  \hspace{1cm} (10)

2.2. Model solving

Use pso to solve the above model, the calculation process of the pso is shown in Figure 1.

(1) Particle coding is mainly divided into three parts. The first part represents the position of the particle in the search space, which represents the optimization variable. The second part represents the position of the particle in the target space, which is the value of each objective function. The third part represents the particle Density information, which is only useful here for particles from external particle swarms.

(2) According to the global temperature, water supply temperature, water supply flow rate, illumination and other boundaries, randomly set the control variables in the particles, and initialize all
particles according to this process.

(3) The fitness function value is the basis for the particle swarm algorithm to guide the search direction. We directly select the objective function as the fitness function, as shown in Equation 1.

3. Example analysis
The power load curve of a large electric customer in Suzhou is shown in Figure 2. The load reduction curve issued by the power supply and demand interactive service platform to a large electric customer’s gateway in a certain period of time is shown in Figure 3. The constraint ranges of air conditioner and illumination operating parameters of this large electric customer is shown in the table 1.

Figure 2. Load curve

![Load curve](image)

Table 1. Constraint range table of equipment line parameter

| Physical parameter                  | Range         |
|-------------------------------------|---------------|
| Air conditioner extremity temperature $\Delta T^1/{}^\circ{}C$ | $\Delta T \leq 4$ |
| Outlet temperature of Chilled water $\Delta T^2/{}^\circ{}C$ | $\Delta T^2 \leq 5$ |
| Chilled water flow $V_r/{}^m^3$     | $63 \leq V_r \leq 125$ |
| Frequency $f_i/Hz$                  | $f_i \leq 50$  |
| $P_L/w$                             | $P_L = 300$   |

Large electric customer’s smart energy gateway uses multi-target equipment group optimal control strategy to control the air conditioner and illumination load. Comparison of load reduction instruction and actual load reduction is shown in Figure 4. Large electric customer load curves before and after regulation is shown in figure 5. The detailed data is shown in Table 2.
Figure 4. Comparison of load reduction instruction and actual load reduction

Table 2 Comparison of peak user valley

| Mode                  | Peak/kW | Valley/kW | Peak-to-valley difference/kW |
|-----------------------|---------|-----------|------------------------------|
| Before regulation     | 187.83  | 7.22      | 180.61                       |
| After regulation      | 159.85  | 7.22      | 152.63                       |
| Change of regulation  | 27.98   | 0         | 27.98                        |
| Percent change of regulation | 14.91% | 0         | 15.5%                        |

From the data in the graph and table, it can be clearly seen that adjusting the equipment according to the strategies studied in this paper can reduce peak load and the peak-to-valley difference greatly while ensuring the user's power demand and meeting the load reduction instructions of power supply and demand interaction service platform.

4. Conclusion

This paper studies the multi-target equipment group optimal control strategy for smart energy gateways for large electric customer. The paper takes the central air-conditioning and illumination load as the research object. Also, it takes user comfort and the number of participate equipment into account and constructs an optimal control model. Also the paper selects pso to solve the model and takes a large electric customer in Suzhou as an example. It can respond to the load reduction instructions issued by the interactive service platform for power supply and demand quickly and accurately. And then achieve the effect of peak reduction while ensuring the power demand of users.

Acknowledgments

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