Research on Peak - Valley TOU Price Based on Demand Side Response

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Abstract. Peak-valley time-of-use (TOU) price is an important method of demand side management. It is the key to implement the peak-valley price reasonably. Firstly, this paper uses the method of cluster analysis to realize the time-period partition, based on the overall price response ability of consumer psychology, a unified user response model is established by considering the time shift ability of different types of load. the response model is amended according to the user's satisfaction. A peak valley tou pricing model is established based on the minimum peak valley difference. The model is solved by genetic algorithm. Finally, an example is given to illustrate the feasibility of the model.

1.Introduction

The peak - valley TOU price[1] is guiding users to adopt reasonable power consumption structure and power consumption mode by changing electricity price. The users will respond certainly on power consumption according to the potential benefits of reasonable TOU price and the load curves will change accordingly. The response of users under reasonable TOU price can effectively balance the load, improve the load curve, and alleviate the problem of power supply shortage during peak period.

This paper uses the method of cluster analysis to realize the time-period partition, based on the overall price response ability of consumer psychology, a unified user response model is established by considering the time shift ability of different types of load. Considering that the actual response of the user will differ from the expected response of the response model, and this change comes from the level of the user's satisfaction, the response model is amended according to the user's satisfaction. Based on the minimum peak valley difference, a decision model of TOU price is constructed. Genetic algorithm is applied to solve the problem，through the example analysis, the model can effectively improve the load curve.

2.Peak valley time division

In this paper, fuzzy clustering analysis method is used to divide the time interval, which effectively avoids the influence of subjective factors and makes the result of time interval division more accurate.

Given an object set $X = \{x_1, x_2, x_3, \cdots, x_n\}$, each object $x_i (i = 1,2,3, \cdots, n)$ contains m characteristics, $x_i = (l_1, l_2, l_3, \cdots, l_m)$. By analyzing the similarity between objects through the characteristics $l_j (j = 1,2,3, \cdots, m)$of objective, the classification results are usually expressed as $C = \{c_1, c_2, c_3, \cdots, c_n\}$. The fuzzy clustering analysis method is divided into three steps, which are as following:

（1）Standardization of characteristic data

Before clustering, each indicator value needs to be standardized so as to unifying each indicator in some common quantified characteristic range.

The quantity standardization usually adopts below calculation method:

$$x_{ij}^{'} = \frac{x_{ij} - \overline{x_j}}{\sigma_j} \tag{1}$$

In the formula,

$$\overline{x_j} = \frac{1}{n}\sum_{i=1}^{n} x_{ij} \tag{2}$$

$$\sigma_j = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}\left(x_{ij} - \overline{x_j}\right)^2} \tag{3}$$

The data are then compressed to the [0,1] interval using the extreme value standardization formula.

(2)Constructing fuzzy similarity matrix

We define r_{ij} to represent the similarity coefficients between object x_i and object x_j, and require $0 \leq r_{ij} \leq 1$, 0 to indicate that they are completely independent or different, and 1 to indicate that they are completely the same. All the similarity coefficients $r_{ij}(i,j = 1,2,3,4,\cdots,n)$ can be calculated to form fuzzy similar matrix R:

$$R = \begin{bmatrix} r_{11} & r_{12} & \cdots & r_{1m} \\ r_{21} & r_{22} & \cdots & r_{2m} \\ \vdots & \vdots & \ddots & \vdots \\ r_{n1} & r_{n2} & \cdots & r_{nm} \end{bmatrix} \tag{4}$$

There are many kinds of distance functions for calculating similarity, this paper uses the absolute value subtraction method:

$$r_{ij} = \begin{cases} 1 & i = j \\ 1 - c\sum_{k=1}^{m}\left|x_{ik} - x_{jk}\right| & i \neq j \end{cases} \tag{5}$$

Among which, we select c properly, making r_{ij} within [0，1] and dispersed.

(3)Clustering analysis

In the process of clustering, it is necessary to accurately determine whether two objects can be grouped into a group. In the process of calculation, there are only two cases: grouped into a group (denoted as 1), cannot be grouped into a group (denoted as 0). To meet this requirement, we need to set confidence level parameter α. Therefore, the concept of α intercept matrix R_α of fuzzy similar matrix R is introduced, and the R_α element $r_{\alpha ij}$ is defined as following:

$$r_{\alpha ij} = \begin{cases} 1 & r_{ij} \geq \alpha \\ 0 & r_{ij} < \alpha \end{cases}, \quad \alpha \in [0,1] \tag{6}$$

We select proper α value, and then make α gradually reduce from 1, according to the α interception relationship to do dynamic clustering, until the number of clustering is 3, that is, the result of the division of peak, flat and valley.

3.User response model

3.1.Overall price response capability of users

There is a minimum perceivable difference in the user's response to the price. Within this difference threshold range, the user is almost insensitive to price changes, which is called insensitive range. When the price change exceeds the difference threshold value, the user will respond to it actively, that is, the linear range; when the price change reaches the saturation threshold, the user response will reach a saturated state, which is basically unchanged, that is, the saturation range[2]. The user's response to electricity price is shown in Figure 1.

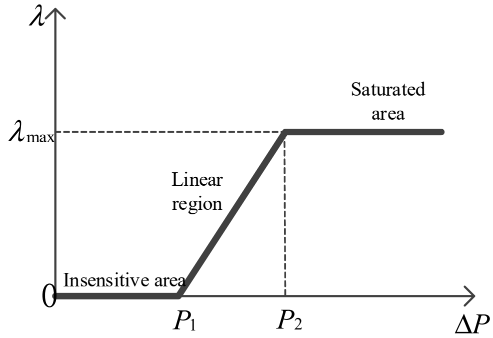

Figure 1. Power user price response curve diagram

In Figure 1, the horizontal coordinate represents the amount of change in price. The longitudinal coordinate represents the rate of change in electric load. The customer demand response capability can be expressed as:

$$\lambda = \begin{cases} 0 & \Delta p < p_1 \\ K_\lambda (\Delta p - p_1) & (p_1 \le \Delta p \le p_2) \\ \lambda_{\max} & \Delta p > p_2 \end{cases} \tag{7}$$

The pricing in peak time period and valley period in peak - valley TOU price is mainly based on the change of linear region in Figure 1. The specific parameters and the slope of linear change need to be obtained through the investigation of all kinds of users in the whole society. The response curve[3] used in this paper is as the following formula:

$$y = -0.3731x + 1.4799 \tag{8}$$

What the above formula reflects is the overall response capability of the whole society to electricity prices, and the response capability of all types of users to electricity prices is different, so load transfer capability is proposed to analyze the specific response of all types of users to electricity prices.

3.2.Load transfer capability of classified users

The load transfer capability of different types of users is different. The load transfer capability of i type user can be defined as: when there is a price difference between time intervals, the ratio of the percentage of the load amount $\Delta Q_{i,k-j}^1$ transferred from high price time interval k to low price time interval j comparing to the load amount $Q_{i,k}^0$ of k time interval before implementing TOU price, divided by the percentage of the price difference $\Delta p_{i,k-j}^1$ between the two time interval comparing to the user average electricity price p_0[4].

$$\varepsilon_i = \left(\frac{\Delta Q_{i,k-j}^1}{Q_{i,k}^0} \right) \Big/ \left(\frac{\Delta p_{i,k-j}^1}{p_0} \right), \quad (\text{if } p_{i,k}^1 > p_{i,j}^1) \tag{9}$$

In the formula, $\Delta p_{i,k-j}^{1} = p_{i,k}^{1} - p_{i,j}^{1}$ is the price difference between time interval k and time interval j.

When the electricity price changes, the load changes under the joint action of the overall price response capability and load transfer capability. The result of the combined action of the two is the final customer response model:

$$Q_{i,k}^{1} = Q_{i,k}^{0} * \left[y * \left(1 - \varepsilon_i\right) \right] \tag{10}$$

3.3.Correction of user response model

There is a certain discrepancy between the actual response of users and the expected results of the response model, and this change comes from the level of user satisfaction. It is generally believed that the user's satisfaction is the acceptability of the new TOU price policy. That is:

$$\Delta Q^{'} = \varepsilon \Delta Q \tag{11}$$

In the formula, ΔQ indicates the change of the amount of electricity consumed by users in each time interval according to the original estimated user response curve. The $\Delta Q'$ indicates the actual load variation amount after considering user acceptability. Through the above formula, the estimated load curve can be revised to get an actual load situation meeting more the actual situation.

The so-called satisfaction of electricity consumption mode[5] is based on the difference between the load curve after response and the original load curve, which can be expressed as following:

$$\varepsilon = 1 - \frac{\int_0^{23} \left| f_{\mathrm{TOU},t}\left(P_{\mathrm{f}}, P_{\mathrm{p}}, P_{\mathrm{g}}\right) - f_t\left(P_t\right) \right| \mathrm{d}t}{\int_0^{23} f_t\left(P_t\right) \mathrm{d}t} \tag{12}$$

4.Determination of TOU price

This paper considers the following constraints: the total electricity consumption remains unchanged before and after the implementation of TOU price; the total profit of the seller after the implementation of TOU price is not lower than the original profit; the total expenditure of the user is not higher than the original total expenditure; the load ratio constraint is fixed; and the valley period price is not lower than the marginal cost constraint. Taking the peak – valley price as the variable and the minimum peak - valley difference as the objective function, with the genetic algorithm to solve the TOU price.

5.Example analysis

This paper adopts 24 hours load data of a day of a provincial capital city in China[4], The data includes the A, B, C three types of users, among which the load transfer capability of type A is relatively poor, accounting for 63%; the period load transfer capability of type B is moderate, accounting for 22%; the load transfer capability of type C is strong, accounting for 15%. The transfer capability coefficient of various loads is as shown in Table 1.

In this paper, we choose the transfer coefficient δ=10%, before implementing tou, the average electricity price of power grid is $p_0 = 0.5647$ yuan/kW·h, fixed load rate is $\eta = 70\%$, valley time cost is 0.2 yuan/ kW·h. Based on the above mentioned fuzzy clustering analysis method, the data is divided into periods, and the initial period division scheme is shown in Table 2.

Table 1. Transfer capacity coefficient of various kinds of loads

	Type A	Type B	Type C
ε_i	0.035	0.07	0.1

Table 2. TOU periods

Period	Corresponding period
Peak time period	08:00-11:00, 16:00-21:00
Normal period	07:00-08:00, 11:00-16:00, 21:00-22:00
Valley period	00:00-07:00, 22:00-24:00

The simulation results show that the optimization results of the electricity price are 0.7328 yuan, 0.4858 yuan and 0.3544 yuan respectively. The load curve before and after the implementation of TOU price is shown in Figure 2.

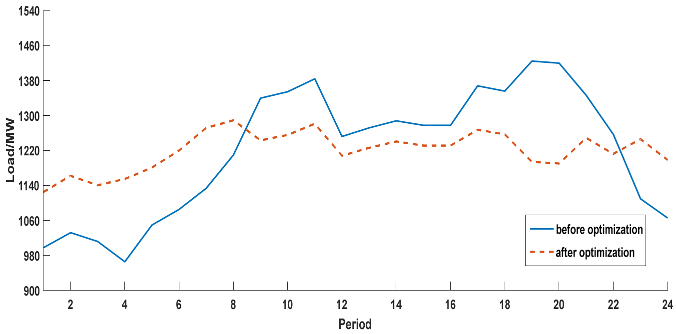

Figure 2. Load contrast curve before and after the implementation of TOU price

Compared with the above data, the peak-valley time-of-use tariff has reduced the peak load by 170 MW, the peak-valley difference has decreased from 574 MW to 205 MW, the load rate has increased to 92.83%. Figure 2 shows that the implementation of peak-valley TOU tariff can effectively adjust the load curve to achieve the purpose of peak cutting and valley filling.

6.Conclusion

This paper uses the method of cluster analysis to realize the time-period partition, based on the overall price response ability of consumer psychology, a unified user response model is established by considering the time shift ability of different types of load. Considering that the actual response of the user will differ from the expected response of the response model, and this change comes from the level of the user's comprehensive satisfaction, the response model is amended according to the user's comprehensive satisfaction. Considering the constraints of power providers and power suppliers, a peak valley TOU price model is established. Under the guidance of this scheme, users change the mode of electricity consumption, improve the load rate, save and slow down the investment of power companies. The load curve is improved through the demand response strategy based on price, which achieves the function of peak shaving and valley filling.

References

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