# Research on user demand response under time-of-use tariff policy based on Sigmoid function

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**Abstract.** The change of user load characteristic is affected by many factors, among which power policy factors have a greater impact on user load characteristic. Based on the Sigmoid function, this paper constructs a response characteristic model of users to time-of-use tariff policy, then analyzes the changes of indicators of load characteristic before and after the implementation of the time-of-use tariff policy based on the summer typical daily load characteristic curve of users in a certain area. The analysis shows that the implementation of the time-of-use tariff policy is conducive to reducing difference between peak and valley, as well as increasing the load rate.

# 1 Introduction

With the rapidly development of the economy, both the demand for power load and the load peak and valley difference is increasing, which is not conducive to the safe operation of the grid and has a certain impact on the power grid. To solve the problem of power supply shortage during peak load periods and reduce the load peak and valley difference, the state came on with relevant price policies to guide users to use electricity effectively and reduce the fluctuation range of load<sup>[1]</sup>.

Nowadays, the electricity price policy issued by the state has the policy of multistep electricity price and peak and valley electric charges and so on, which could ensure the economic operation of grid. Analysis deeply the impact of policy factors on load characteristic will help electrical experts to better grasp the changing rules of load characteristic, provide decision-making basis for solving power demand gaps, and difference between peak and valley<sup>[2-3]</sup>. Based on the load data of Zhuzhou grid, Y. Lan studied the load development status and grid load characteristics, and analyzed the implementation of the time-of-use tariff policy to achieve the peak-filling effect of large industrial users' load<sup>[4]</sup>; reference [5] established and verified the response model of key industry users to the time-of-use tariff policy, and the results show that the rationality of the response model; based on the principle of economics, reference [6] constructed the model of load reduction and transfer of users after the implementation of the time-of-use tariff policy, and analyzed the response degree of users to time-of-use tariff policy; reference [7] analyzes the interactive response characteristics of users under the time-of-use tariff policy based on the interaction behavior pattern and response potential of residential electricity consumption in the demand response. For the influence of time-of-use tariff policy on the load characteristic of users, most of the above references do not analyze the impact of the implementation of price policy on typical daily load characteristics indicators.

Based on the actual power load data of users in a certain area, and combined with the user response characteristic model, this paper analyzes the changes of the typical daily load characteristic curve before and after the implementation of the time-of-use tariff policy, reflecting the impact of policy implementation on load characteristic indicators.

# 2 User response characteristic model based on Sigmoid function

# 2.1 Sigmoid function

The Sigmoid function is an S-shaped curve, which has a wide range of applications in logistic regression and artificial neural networks. It can map variables to (0, 1) and the mathematical form is shown in equation (1):

$$f(x) = \frac{1}{1 + e^{-x}} \tag{1}$$

In the formula, where x is a variable. And, the Sigmoid function image is shown in Fig. 1.

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Fig. 1. Sigmoid function image

As can be seen from the above figure, the Sigmoid function is continuous, smooth, strictly monotonous, symmetric with (0,0.5) as the center, and is a very good threshold function. The threshold of Sigmoid increases slowly near the two ends, and grows faster near the center point, that is, as the tariff difference during peak and valley periods increases, the user's response level increases monotonously: when the tariff difference during peak and valley periods is smaller, the user's response level is low; and as the tariff difference during peak and valley periods increases, the user's response degree gradually increases. When the electricity price difference in each period of peaks and valleys is greater than a certain degree, the user response tends to be saturated, that is, as the electricity price difference increases, the user's response grows more and more slowly.

#### 2.2 User response characteristic model

It can be seen from the Sigmoid function image that when x approaches near-negative infinity, y approaches 0; when x approaches positive infinity, y approaches 1; when x=0, y=0.5. When x exceeds the range of [-6,6], the function value does not change substantially, which does not better describe the user's response characteristics to the time-of-use tariff policy. Therefore, while studying the response characteristic of the user load change to the electricity price change based on the Sigmoid function, the user response characteristic model needs to be constructed; since equation (1) cannot accurately reflect the user's response level to the time-of-use tariff policy, then equation (1) is needed to improve, and the improved user response characteristic model is shown in equation (2):

$$q(x) = \frac{\lambda}{1 + e^{\frac{-(x-\alpha)}{\delta}}}$$
(2)

In the formula, where x is the electricity price difference; and q(x) is the load transfer rate, that is, the ratio of the load reduced by the user at a certain time to the total load after the implementation of the time-of-use tariff policy, unit: %;  $\alpha$  is a center point abscissa of the Sigmoid function;  $\delta$  is the degree of tilt of the Sigmoid function, which reflects the user's response degree to the tariff policy;  $\lambda$  is selected according to the value of the maximum load transfer rate.

# 3 Case analysis

In terms of seasons, the year is divided into four stages. Among which, March, April, and May are spring; June, July, and August are summer; September, October, and November are autumn; and December, January, and February are winter. The maximum load day is selected as the typical day. Due to the high temperature in summer, users use a lot of refrigeration equipment such as air conditioners, and the load is more than the other three seasons. Due to the implementation of the time-of-use tariff policy can achieve peak shaving and valley filling, for better test the effect of the implementation of the timeof-use tariff policy, this paper selects the typical summer day to analyze the impact of the implementation of the time-of-use tariff policy on user load characteristic and the changes of load characteristic indicators. Among which, the load characteristic curve of the typical summer day is shown in Fig. 2.



Fig. 2. User load characteristic curve of the typical summer day in a certain area

As can be seen from the above figure, the user's power load has a clear peak load value and a low valley load value, and the difference range between peak and valley is large. What's more, the load characteristic indicators are shown in Table 1.

typical day	July 28th
the maximum load/MW	140.25
the minimum load/MW	39.45
the load peak-to-valley difference /MW	100.8
the rate of load peak-to- valley difference/%	71.86
the load rate/%	63.92

 
 Table 1. Load characteristic indicators of typical summer days of users in a certain area

According to the summer typical load characteristic curve of the users in the region, the peak periods, the valley periods and the flat periods can be divided, and the specific schemes for dividing the typical daily time periods can be obtained as shown in Table 2.

 Table 2. Typical summer day time division scheme for users in a certain area

period	division scheme	duration of each period/h
peak period	10:00-13:00、16:00-23:00	11
flat period	9:00-10:00、13:00-16:00、 23:00-0:00	4

valley period	0:00-9:00	9
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It can be obtained from Table 2 that the user's power load is mostly distributed in the peak period. From the tariff list in the region, it is known that the tariff during the peak periods is 1.4 yuan/kWh, the tariff during the flat periods is 0.9 yuan/kWh, and the tariff during the valley periods is 0.4 yuan/kWh. Assume that the parameters  $\lambda_{\rm s}$   $\delta_{\rm s}$   $\alpha$  of the user response model are 0.2, 0.5, and 0.5, respectively, that is, when the price difference of peak-flat periods and flat-valley periods is 0.5 yuan/kWh, the user's load transfer rate is 0.1 times of the total load after the implementation of the time-of-use tariff policy.  $\lambda$  is determined by the value of the maximum load transfer rate,  $\alpha$  is determined by the threshold of the electricity price difference, and  $\delta$  is determined when the load transfer rate reaches 90% and the peak-to-valley tariff difference is 1 yuan/kWh.

By analyzing the impact of time-of-use tariff policy implementation on user load characteristic in the region, then taking advantage of the user response characteristic model to calculate the load reduction in period of peakflat-valley, and we can obtain the typical daily load curve of users in the region after implementing the time-of-use tariff policy, as shown in Fig. 3.





As can be seen from the above figure, before and after the implementation of the time-of-use tariff policy, the trend of user electricity load changes is roughly the same. After the implementation of the time-of-use tariff policy, the peak value of user's electricity load has shifted and decreased, while the load valley value has increased, and the load peak and valley difference has decreased.

Before and after the implementation of the time-of-use tariff policy in the region, the comparison among the changes in users' load characteristic indicators, as shown in Table 3.

 Table 3. Comparison of characteristic indicators of user's

 electricity load before and after implementation of time-of-use

 tariff policy

load characteristic indicators	before the implementation of the time-of-use	after the implementation of the time-of-use	changes (2) - (1)
comparison	tariff policy (1)	tariff policy (2)	
the maximum load/MW	140.25	129	-11.25
the minimum load/MW	39.45	53	13.55

the load difference between peak and valley /MW	100.8	76	-24.8
the rate of load difference between peak and valley /%	71.86	58.71	-13.15
the load rate/%	63.92	67.52	3.6
<b>.</b> 1	0 1		

It can be seen from the above table that after the implementation of the time-of-use tariff policy, the maximum load, the difference between peak and valley and the rate of the difference between peak and valley of the user are reduced, while the load rate and minimum load are increased. The decrease of the load peak and valley difference is beneficial to alleviate the power supply pressure of the power system during the peak periods of power consumption; the load rate increases, which can reduce the fluctuation of the load curve and increase the utilization efficiency of the power equipment by users.

# 4 Conclusions

Based on the actual load data of users in a certain region, this paper analyzes the response degree of users to the time-of-use tariff policy, and the following conclusions can be obtained:

(1) After the implementation of the time-of-use tariff policy, the difference between peak and valley of user's electricity load is reduced, but the load rate is increased, thereby improving the utilization efficiency of the power system and the utilization efficiency of the power equipment by users; in addition, the implementation of time-of-use tariff policy can cut peak and fill valley, alleviate the contradiction between power supply and demand, suppress unreasonable demand for electricity.

(2) The implementation of the time-of-use tariff policy will help guide users to use electricity in an orderly manner, and help users establish a correct concept of electricity consumption, which will help promote energy development.

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