Identification classification of power user demand response effect based on electricity acquisition data

Rui Ge¹, Yiding Jin¹, Changyou Feng¹, Zhao Zhao², Nan Wang² and Pengfei Li³*

¹ State Power Dispatch Control Center, Beijing, 100031, China
² State Grid Electric Power Co., LTD. In Hebei Province, Shijiazhuang, Hebei, 050021, China
³ School of Economics and Management, North China Electric Power University, Beijing, 102206, China
*Corresponding author’s e-mail: huadianlipengfei@163.com

Abstract: In recent years, the great potential of power demand-side resources in the power system has been gradually recognized and exploited, especially the demand response of power users. Demand-side management has received more and more attention. In order to clarify the rationality of the requirements response project design and the degree of implementation of the expected effect, this paper studies the demand response characteristics of power users’ electricity load. Based on the processing of load data using the analysis technology, the demand response feature indicator is proposed, taking into account the response capacity, response speed, response cycle, and using K-means clustering method to realize the identification and classification to the effect load response of users, and finally give power users demand response interactive Policy.

1. Introduction
With the development of social economy and the progress of science and technology, the energy crisis and environmental pressure are becoming more and more serious, the modern power system is also facing higher challenges, the concept of smart grid has emerged, and gradually become the research and development of power industry. As one of the most important components of smart grid, the great potential of power demand side resources in the power system is gradually recognized and explored, especially the demand response of power users, which directly reflects the main characteristics of smart grid "smart interaction", which has received great attention in the world. As a result, It is necessary to study the demand response characteristics of power users and classify them so as to provide different incentives for different users.

Literature [1] shows that in recent years, in order to alleviate the contradiction between the rapid growth of power demand and the difficulty of power grid expansion, demand side management has received more and more attention; the literature [2] analyzes the basic theory of user behavior analysis methods. The advantages and disadvantages of different clustering algorithms, the choice of distance metrics and the effect of index evaluation function are studied. The literature [3] proposes a quantitative evaluation method for demand response potential considering the statistical characteristics of load electricity consumption. The literature [4] designed a A preference strategy based on information entropy and feature correlation coefficient; the literature [5] uses the optimized K-means algorithm to select the initial value. In [6-8], the users are divided into industrial, commercial and civil loads. The categories are more general and do not specifically combine the power consumption characteristics and
response characteristics of each user. The demand response feature extraction indicators established in these papers rarely take into account the demand response speed and response period of the power load.

In this paper, based on the demand response characteristics of electric load, based on the data analysis technology to deal with the load data, the demand response extraction feature index is proposed by considering the response capacity, response speed and response period, and K-means clustering method is adopted. The user load is classified, and recommendations are made based on the classification to implement demand response items for different categories of users.

2. The status of demand-side management and development in China
At present, China's power demand side management work is roughly divided into three categories: the first category is the construction of power demand side management related policy system; the second category is the key organization to implement grid enterprise power demand side management target responsibility system, regional industrial area power demand Side management work pilot, urban power demand side management comprehensive pilot, power demand response pilot; the third category is power demand side management training, publicity, international cooperation and other work.

With the large-scale construction of new energy power and access to the power grid, user-side energy storage technology, power-saving and load-saving technology, etc. urgently need innovation, and innovation and improvement of power demand side management technology standards need to be accelerated.

3. Demand-side response based on load management
The demand side response based on load management mainly implements the demand side response process of power users through two methods: Interruptible Load (IL) and Time of Use (TOU).

3.1 Interruptible load

3.1.1 The connotation of interruptible load. Interruptible load is the load that allows a conditional power outage by contract or the like. With the gradual liberalization of the demand side, the load can be interrupted as a virtual backup power generation capacity resource and transmission capacity resource, which is receiving more and more attention in peak shaving and lowering congestion. As an emergency spare capacity resource, especially in dealing with small-probability and high-risk capacity accidents, it is very important to interrupt the load to participate in the backup service market.

3.2 Dynamic time-sharing electricity price

3.2.1 The connotation of dynamic time-sharing electricity prices. Time-sharing electricity price is an effective countermeasure to guide power users to adopt reasonable electricity structure and electricity consumption method by means of electricity price signal. At present, the measure has been playing an increasingly important role in the economic management of power industry in the world. The implementation of dynamic time-sharing electricity price is a reflection of the time difference between electric energy commodities, which reflects the law of commodity value and the principle of market economy, as well as the principle of fair burden of users. Theoretically, the implementation of real-time electricity prices is most likely to achieve the greatest total social benefits, can best play the effective allocation of electricity prices to resources.

4. The User’s multidimensional recognition classification by electrical responsiveness

4.1 Identify the target user base and typical users participating in the assessment:
(1) Select the corresponding power user load to determine the range of the assessment area;
(2) Identify the needs response projects to participate in the assessment;
(3) Obtain the historical load data of 96 points from the different types of load required from the electricity information collection system and the 96 point load data after the implementation of the demand response project.

4.2 Data cleaning: Check the data for missing or outliers, and cull data with missing or outliers.

4.3 Pre-processing data

(1) Predict the maximum \( q_{\text{max}}^k \) and minimum \( q_{\text{min}}^k \) values of the original trend of the load during demand response through the historical data of the load, including the following steps:

a, measure the growth rate of the annual load \( r \), the expression is as follows:

\[
r = (n-1)\left(\frac{Q_n - Q_1}{Q_1}\right) - 1
\]

In the formula (1), \( Q_n \) for the n-th-year total load, \( Q_1 \) for the first year of total load.

b, based on the number of 96-point load data for the year \( n+1 \) year (year in which the demand response project was implemented) considered the historical load growth rate, as follows:

\[
q_{n+1}^{k,s} = q_n^{k,s} \times (1 + r)
\]

In the formula (2), \( q_n^{k,s} \) is the load value for the nth year kth day, \( q_{n+1}^{k,s} \) is the load value of the n-plus1 year k day, the n-plus1 year for the implementation of the demand response project year.

c, Identify and get the predicted maximum value \( q_{\text{max}}^k \) and minimum \( q_{\text{min}}^k \) of the 96th point load per k days in the n+1th year (the year in which the demand response project is implemented)

(2) According to the actual collected data of 96 points per day in the n+1th year, the maximum \( q_{\text{max}}^k \) and minimum values \( q_{\text{min}}^k \) and the average value \( q_{\text{ave}}^k \) of the load per k day are identified and obtained.

4.4 The index of user demand response feature

(1) Peak load reduction rate: the ratio of the peak user load after the real-time demand response project.

\[
PR^k = \left(\frac{q_{\text{max}}^{k'} - q_{\text{max}}^k}{q_{\text{max}}^k}\right) \times 100\%
\]

In the formula (3), \( PR^k \) is the peak load reduction rate in the kth day, and \( q_{\text{max}}^{k'} \) is the peak of the load before and after the load for the kth day user load response.

(2) Peak-to-Valley Difference: The ratio of the peak-to-valley difference of the user load before and after the demand response project is implemented.

\[
PtV^k = \left(\frac{q_{\text{max}}^k - q_{\text{min}}^k}{q_{\text{max}}^{k'} - q_{\text{min}}^{k'}}\right) \times 100\%
\]

In the formula (4), the \( PtV^k \) is the peak-valley difference rate for the k-day, with the peak of the load before \( q_{\text{max}}^k \) and after \( q_{\text{max}}^{k'} \) the load for the k-day user response, and the grain load before \( q_{\text{min}}^k \) and after \( q_{\text{min}}^{k'} \) the load for the k-day userload response.
(3) Load rate: the average daily load rate after the implementation of the demand response project.

$$LF^k = \frac{q_{ave}^k}{q_{max}^k} \times 100\%$$  \hspace{1cm} (5)

In the formula (5), $LF^k$ is the the load rate for the $k$ day, and the peak of the load before $q_{max}^k$ and after $q_{ave}^k$ the load for the $k$ day, $q_{ave}^k$ is the average of the load for the $k$ day.

(4) Response indicator: A comprehensive indicator that reflects response conditions such as response rate and response period after a demand response project is implemented. The rate and duration of the response are reflected by a series of matrices of 0 and 1.

$$RS^k = \begin{cases} 1, & PR^k > \alpha \\ 0, & PR^k \leq \alpha \end{cases}$$  \hspace{1cm} (6)

In the formula (6), for the $k$ day of the $RS^k$ response situation, the response is 1, does not respond to 0, $PR^k$ for the $k$ peak load reduction rate, for the set $\alpha$ threshold. $\alpha$ Represents the permissible range of normal fluctuations in peak and load.

As the characteristic of user interaction, the above indicators can reflect the change of the user's electricity behavior and the degree of change under the change of electricity price policy, so it can be used to analyze and predict the power consumption pattern stake of different categories of users, and also reflect the contribution of the user to the load curve after the response of the demand. In order to convert the original data matrix into a feature matrix, the characteristic matrix is used to complete the clustering algorithm, the user behavior classification and analysis.

The four feature indicators calculated by the load per day are a sample, and the clustering matrix of the load curve feature indicator is $Y_{365\times4}^{\times4}$.

4.5 User clustering analysis

The four feature indicators calculated by the user per day as a sample, then useri represents the load curve feature indicator's clustering matrix. Clustering using $Y_{365\times4}^{\times4}$ the K-means clustering method. Matrix is input, and euclidean $Y_{365\times4}^{\times4}$ distance is the similarity criterion for clustering. Randomly select $Y_{365\times4}^{\times4}$ ksamples as the initial cluster center to calculate the distance from each sample to the initial cluster center, the sample is grouped into the smallest class, and then recalculate the cluster centers. Repeat the calculation of distance calculations, classification, and clustering centers until the specified number of iterations is reached or the distance within the class is no longer reduced, and the number of classes is completed with $k$ clustering.

The range of values for the number of clusters, $k$, is $to$, representing the number of samples. The final number of clusters is determined by calculating Silhouette the effectiveness indicator of the cluster.

5. Conclusions

It is important to classify and identify users under the condition of demand response. In this paper, the feature extraction index is designed from the response capacity, response rate and response period as the clustering basis, and K-means clustering algorithm is used to continuously change the $K$ value, improve the clustering accuracy, and obtain a more optimized clustering effect. And the correct number
of classifications helps to analyze the power usage behavior of different users in response to demand and the potential of users to participate in grid interaction.

The user's clustering results can be clearly divided into different categories, and each type of resident user has obvious power usage habits and characteristics, indicating that the characteristics of user interaction in different categories of demand response are different, and the potential of interaction is also different. For active responders, incentive policies can be increased, certain subsidies can be given, and such users can be encouraged to participate in peak shaving; for ordinary responders, corresponding demand response projects can be developed to maximize their response potential and achieve more with such users. Interaction; for those who respond negatively, they should improve the electricity price policy, publicize the demand response advantage, and make it participate in the power policy of the power grid as much as possible while preserving the basic electricity consumption benefits. According to the power consumption characteristics of different users, different peak-peak clipping peak scheduling strategies can be provided for the power grid, which is also the basis for the future power grid pricing.

Acknowledgements
Science and Technology Project of State Grid Corporation of China, Integrated Operation Control Strategy of Cross District Whole Network Adapting to the Development of New Energy, Number: SGTYHT/16-JS-198.

References
[1] Liang Tiantian, Gao Siwei, Wang Wei. Application of Power Demand Side Management in Smart Grid[J]. Electric Power Automation Equipment, 2012, 32(5): 81-85.
[2] Jia Mengyang. User behavior analysis and interactive strategy research considering user responsiveness [D]. 2017.
[3] Ren Bingzhen, Zhang Zhengao, Wang Xuejun, et al. Evaluation method of peak response potential based on demand data collected by electricity[J]. Electric Power Construction, 2016(11).
[4] Xu Liangjun, Zhang Xiaodi, Wang Lijun. Analysis of User Classification and Power Consumption Behavior Based on Cluster Analysis[J]. Shanxi Electric Power, 2016(4): 23-27.
[5] Cui Xiaoyun, Wang Huanhuan, Qian Shenyi. Application of Improved K-means Method in Customer Classification[J]. contemporary computer, 2016(24).
[6] Li Yaping, Wang Wei, Guo Xiaorui, et al. Potential Response Potential of Regional Power Grid Based on Multi-Scenario Evaluation[J]. Power System and Clean Energy, 2015(7):1-7.
[7] Su Weihua, Zhang Liang, Su Huiling, et al. Research on load forecasting method considering demand side management[C]// China University of Higher Education Power System and Automation Professional Academic Conference and China Electrical Engineering Society Power System Professional Committee Year Will. 2010.
[8] Zhou Jiange. Research on load forecasting method considering demand side management [D]. Shanghai Jiaotong University, 2012.