PRECISE ANALYSIS OF INTERRUPTION RESPONSE RATE AND INTERRUPTIBLE CAPACITY OF LARGE USERS

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The research of interruptible features of large users is the basis to make dispatching plan of interruptible loads in a grid emergency, including peak shifting and frequency modulating. Interruption response rate and interruptible capacity are the critical characteristics of interruptible loads. In order to analyze the characteristics of maximal interruption rate and maximal interruption capacity of large users, a quadratic classification model was used to cluster the daily load data of users. Besides, the fuzzy C-means clustering method was adopted for each classification. The first classification is used to separate the interruption response data from the conventional data. The second classification aims to obtain the refined interruption patterns. Then the response rate and interruptible capacity were analyzed from two dimensions which are time dimension and industry dimension. The results show that the quadratic classification model can effectively excavate the users' maximal response rate and maximal interruptible capacity.

Keywords: Fuzzy C-means clustering method, quadratic classification model, interruptible loads, interruption response rate, interruptible capacity

1. Introduction

No.9 document of electricity reform proposes to steadily promote the reform of electricity selling side and orderly open the electricity selling business to social capital in China, which provides new opportunities for the development of demand response [1]. The implementation of demand response provides another solution to meet the growth of electricity demand, which only depends on the increase of installed capacity before [2]. Developing Interruptible Load (IL) to provide ancillary services is the key to distribution market transactions. As an important means of Demand Response (DR), IL has been widely used in the absorption of high permeability renewable energy [3-4], peak-shaving of power grid [5], optimal economic dispatch of power system [6-7], and coordinated

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planning of integrated energy system [8]. These studies are based on the condition that the user's interruptible characteristics are known. In the actual operation process of the power system, whether the user has interruptible properties and its specific interrupting capacity, response rate and other parameter information must be obtained by mining and analyzing a large number of load data.

IL is a method of interrupting part of the power supply after the interruption request signal is sent to the user by the implementing agency during the peak period of the power grid according to the prior contract agreement between the supplier and the demander [9]. Power companies sign a power purchase agency contract with users in a trading cycle, and issue interruption response plans to users at the same time, specifying contract validity, each interruption time, advance notification time, interruption capacity ceiling, compensation costs and other information [10]. According to the characteristics of historical load data, industry characteristics and electricity nature of users, the power selling company should select the target users and formulate a reasonable transaction plan. Users also need to measure their interruptible capacity, interruption rate and interruption cost, so as to decide whether to sign a contract with the power company [11]. Therefore, it is of great significance to study the law of historical load data of users and to mine interruptible characteristics from multiple dimensions, whether for power selling companies or users. IL is generally applicable to large-scale industrial and commercial users, so this paper takes large-scale users as the research object and analyses their interruptible characteristics.

At present, there are some studies on load characteristics of power system. Literature [12] proposes a framework for evaluating the sensitivity of hypothetical demand response plans to consumer preference performance. It tests whether consumers have realized the plan to determine the potential of user demand response but ignores the diversity of DR modes and does not refine the analysis of interruptible loads. Document [13] regards the typical daily response curve of users as a data set based on spectrum clustering and divides the response level of users according to the clustering center of each category but does not make quantitative analysis of interruptible characteristics. Literature [12] and literature [13] are both studies conducted in a free competitive electricity market environment, and the response characteristics of users will be constrained by the economic level. Based on historical load data, this paper analyses the interruption response characteristics of users under physical constraints and existing price and incentive policy constraint. The essence of interruptible load is that it can interrupt the power supply when the power system needs to meet the requirements of safe operation or other business requirements of the power system. Large users can not complete load removal instantaneously, but after a certain response time, the larger the interruption response rate, the faster the load removal and the better the

system operation; different users provide different interruptible capacity at different times, and the larger the interruptible capacity, the greater the contribution to the system interruption demand. Therefore, from the physical level, when selecting interruptible load to participate in the optimal operation, the system mainly considers the maximum interruption rate that large users can achieve and the maximum interruption capacity that can be provided at all times. In order to mine the maximum interruption rate of users, it is necessary to identify the part of data that has interruption response from the existing power data, then calculate and analyze the interruption response data to find out the fastest rate of load decline, i.e. the maximum interruption rate. For the maximum interruption capacity, it is also necessary to separate the conventional power consumption data from the data after interruption response. By comparing the difference between the conventional load curve and the load curve after interruption response, the maximum interruption capacity is determined. However, the user's electricity consumption data is too large to be comparatively analyzed one by one. Therefore, the clustering analysis method suitable for processing massive data is adopted to extract the typical user's electricity consumption patterns.

In this paper, fuzzy C-means clustering method (FCM) is used to cluster the historical load data of a single user, and a quadratic classification model is proposed. The number of clusters is set at 2 for the first clustering, and the number of classifications is determined by the validity function for the second clustering. The characteristics of interruptible capacity and interruption response rate of large users are studied, and the influences of industry factors and seasonal factors on the interruption characteristic are also analyzed.

2. Principle of Cluster Analysis

The purpose of clustering is to divide the original object into several clusters. The objects in the same cluster are similar, and the objects in different clusters are different. At present, there are many mature and effective clustering algorithms [14-15]. The general clustering algorithm is a kind of hard partition, which strictly divides every object to be identified into every category, which has either or nature. In fact, hyperspectral target has intermediary in shape and genus, and there is no exact boundary to distinguish. FCM can take into account the degree of membership of each sample, and make soft distinction, so as to better classify. Thus, in this paper, FCM method [16] is used for clustering analysis, and clustering validity function is introduced to determine the optimal number of classifications.

2.1 FCM method

In the FCM method, each sample point cannot be strictly divided into a certain category but belong to a certain category [17] with a certain degree of membership. The basic idea of FCM is to adjust (U, V) iteratively to minimize the

objective function J. U is the membership matrix of users and V is the clustering center. The specific optimization model is as follows:

$$\min J(U,c) = \sum_{i=1}^{c}\sum_{j=1}^{n} u_{ij}^2 d_{ij}^2 \tag{1}$$

s.t

$$\sum_{i=1}^{c} u_{ij} = 1 \tag{2}$$

$$d_{ij} = \left\| x_j - v_i \right\| \tag{3}$$

$$u_{ij} \in [0,1] \tag{4}$$

Among them, u_{ij} denotes the membership degree of user j in class i, and d_{ij} denotes the distance between user j and cluster center i.

2.2 Clustering validity function

In clustering analysis, the number of clusters of original data cannot be determined by FCM method. The number of clusters C needs to be given beforehand. The determination of clustering number C and the rationality of the method are the validity of clustering.

In this paper, cluster validity function F_C is used to determine the number of clusters. F_C is defined as follows:

$$F_C = \frac{1}{n}\sum_{i=1}^{c}\sum_{j=1}^{n} u_{ij}^2 \tag{5}$$

The closer the value of F_C is to 1, the smaller the fuzziness of clustering, the better the clustering effect. The clustering validity function values corresponding to all possible classifications are calculated, and the number of classifications C corresponding to F_C closest to 1 is selected as the clustering number of the original data set.

3. Quadratic Classification Model

In order to evaluate the maximum interruption rate and capacity of industrial and commercial users, a quadratic classification model is used to mine the characteristics. The model has two clustering analysis, the first clustering is used to separate the general load of large users and the load after interruption response, so the number of the first clustering is 2. The second clustering is used to cluster the load data after interruption response, and several typical interruption response curves of the user are obtained. The number of clusters is determined by the validity function. The interruption rate and interruption capacity of the user are analyzed based on the conventional power consumption curve obtained by the first clustering.

3.1 Twice classification

Daily load curves of key large users in a period of time with frequent interruption responses are collected as original data sets. Some of the daily load curves in the original data are those in the normal operation state, and some are those after the interruption response of the user (the interruption response is also regarded as the interruption response when the user takes a rest or reduces production at the weekend). In the normal operation state, the power consumption regularity of industrial and commercial users is strong, and the daily power consumption is larger than the daily power consumption after interruption response. Therefore, the original data can be divided into routine operation data and interrupt response data by FCM method. Using 96-point daily load data as feature vectors, the original data set is clustered and analyzed, and the final membership matrix U and clustering center V are obtained.

After the first clustering, the user's conventional power consumption data and interruption response power consumption data have been separated from the original data. However, the interruption modes of users are various. In order to analyze the interruption characteristics of users in detail, the data of interruption response obtained by the first clustering are clustered again. The optimal number of clusters is determined by clustering validity function, and many typical patterns of interruption response of users can be obtained.

3.2 Refined analysis

The typical load curve of the single user can be obtained by the first clustering and the second clustering. The typical interruptible curve of the user can be obtained by subtracting the interruption response from the conventional power load. Several types of interruptible curves are compared and the maximum interruption capacity curve corresponding to each time is selected to obtain the maximum interruption capacity curve of the user; the wave of the load curve after interruption response is compared. Motivation rate, the maximum interrupt response rate of the user can be obtained. The specific mining process is shown in Fig. 1. In the typical loads curve, load 1 represents the user's conventional load curve, and load 2.1 to load 2.3 represents the user's three typical interruption response after-load curves.

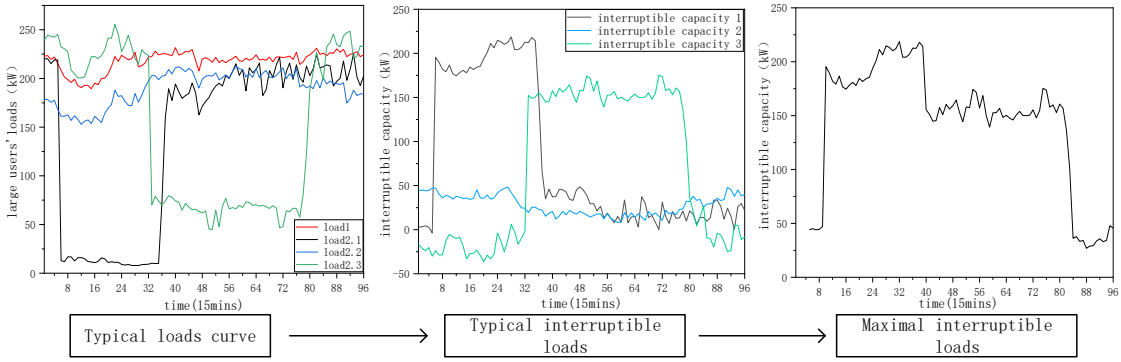

Fig. 1. The mining process of interruptible features

In order to study the influence of industry factors and seasonal factors on the interruption response characteristics of large users, several users belonging to different industries can be selected to study their interruption response characteristics, compare and analyze the relationship between industry characteristics and interruption response, or study the power consumption data of the same user, mine their power consumption characteristics in different seasons, and compare the similarities and differences of several power consumption characteristics.

4. Case Study

Six users in a city of Jiangsu Province were selected to study interruptible characteristics. User 1, user 2 and user 3 belong to cotton, chemical fiber textile and finishing industry, user 4, user 5 and user 6 belong to stainless steel and similar daily metal products manufacturing industry. Because summer and winter are the peak periods of electricity consumption in a year, the probability of interruption response is higher. Therefore, 96-point daily load data in July and December are selected for analysis.

4.1 Interruption response rate

The maximum interruption response rate for each user in July and December is shown in Table 1.

Table 1

Maximal interruption response rate

Large users	1	2	3	4	5	6
July (kW/min)	6.18	51.45	12.96	0.61	1.65	12.78
December (kW/min)	23.1	12.96	13.54	0.50	5.73	5.73
Maximum (kW/min)	23.1	51.45	13.54	0.61	12.87	12.87

From the perspective of industry dimension, Table 1 shows that the response rates of user 1, user 2 and user 3 are higher than those of user 4, user 5 and user 6. Overall, the interruption rate of cotton, chemical fiber textile and finishing industry is higher than that of stainless steel and similar daily metal

products manufacturing industry. Comparing different users in the same industry, for cotton, chemical fiber textile and finishing industry, the interruption response rate of user 2 is the highest, up to 51.45 kW/min, followed by that of user 1, 23.1 kW/min, and that of user 3 is the lowest, 13.54 kW/min. It can be seen that the maximum interruption response rate of user 2 is the same as that of user 3. For stainless steel and similar daily metal products manufacturing industry, the largest interruption response rate is 12.87 kW/min for user 6, and the smallest interruption response rate is 0.61 kW/min for user 4. It can be found that the maximum interruption response rate of users is related to their industry, but industry factors cannot determine the interruption rate of users, and the interruption rate of users in the same industry may still vary greatly.

From the time dimension of table 1, for users in cotton, chemical fiber textile and finishing industry, the maximum interruption rate in July of User 1 is less than that in December, the interruption rate in July of User 2 is higher than that in December, while the interruption rate in July of User 3 is close to that in December. The change of interruption rate of users in this industry is not consistent in time dimension, so it is necessary to analyze specific users. For stainless steel and similar daily metal products manufacturing industry, the maximum interruption rate in July is generally greater than that in December. The effect of seasonal change on the interruption rate of users in this industry is basically the same.

4.2 Interruptible capacity

The maximum interruptible capacity of each user in July and December is shown in Fig. 2.

From the perspective of industry dimension, Fig. 3 shows that interruptible loads of cotton, chemical fiber textile and finishing industry are flexible and diverse, while the maximum interruption capacity of users in stainless steel and similar daily metal products manufacturing industry has certain similarities, and the maximum interruption capacity of users has a certain relationship with their industries. Taking the maximum interruptible load curve in July as an example, the interruptible period of User 1 is concentrated at 9 to 23 points, and the maximum interruptible load curve is relatively stable during this period, and the maximum interruptible load is between 90 kW and 100 kW; User 2 can realize fast interruption of 790 kW load at 17 points, and the maximum interruptible load between 17 and 22 points is around 200 kW; User 3 can achieve fast interruption of 790 kW load at 20 points to 24 points. There is a certain amount of interruptible load. The interruptible load increases steadily from 100 kW to 180 kW. The maximum interruptible load curves of the three kinds of users are different, which shows that the production activities of the industry are more flexible, and the specific production plan can be arranged by each user independently, without the restriction of the industry itself.

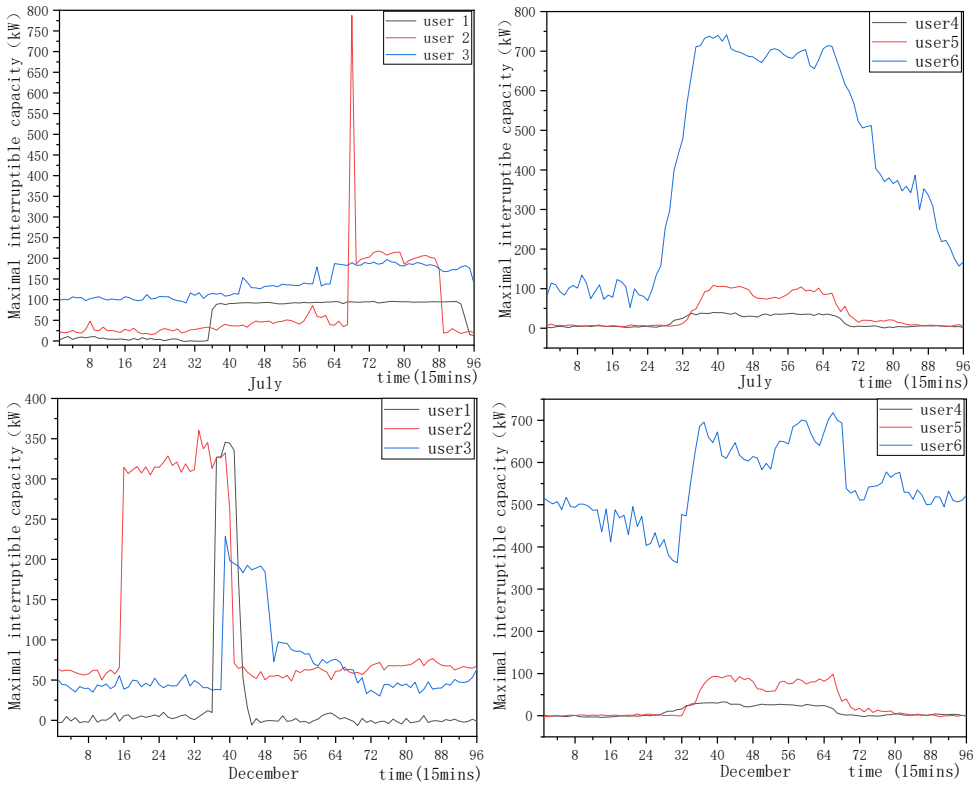

Fig. 2. Maximal interruptible capacity curve

This is also part of the reason for the high interruption response rate of users in this industry. For the stainless steel and similar daily metal products manufacturing industry, the peak period of users is concentrated at 9:00 to 14:00.

Taking July data as an example, the interruptible load of User 4 is low, only 40 kW in peak period and close to 0 in other periods; the maximum interruptible load of User 5 is close to 110 kW in peak period and almost no interruptible load in other periods; the maximum interruptible load of User 6 is as high as 740 kW in peak period, and the maximum interruptible load of User 6 is not more than 200 kW in other periods. It shows that the production regularity of stainless steel and similar daily metal products manufacturing industry is strong, and the production plan of each user is relatively fixed, which also explains why the interruption rate of users in this industry is relatively low.

Fig. 2 also shows that for user 1, user 2 and user 3, the maximum interruptible load curve in July is quite different from the maximum interruptible load curve in December. The peak value of maximum interruptible load is different from the peak period of interruptible load. It shows that seasonal variation makes the user's production plan change, thus affecting the nature of

interruptible load. User 5 and user 6 had the same interruption peak period in July and December, which ranged from 9 to 16. The maximum interruptible load curve of user 4 and user 5 in July was basically the same as that of December, indicating that seasonal variation had little influence on their production activities, while the peak interruptible load of user 6 in December was higher than that in July. The peak value decreases, but in the non-peak period, the maximum interruptible load in December is much larger than the maximum interruptible load in July, indicating that seasonal change has a certain impact on the maximum interruptible capacity value of the user.

5. Conclusions

In this paper, FCM method is used for clustering analysis, and the maximum interruption rate and capacity characteristics of single large user are effectively excavated through the secondary classification model. The interruptible load characteristics of large user are studied from the industry dimension and time dimension, and the influence of industry attributes and time factors on load interruption characteristics is discussed. Ring. However, there are still some shortcomings in this study. The 96-point daily load data is used in the example. This paper analyzes the interruptible characteristics of single user, which provides the basis for the establishment of IL contract, and is of great significance to large users and power companies. Considering that a large number of users often participate in the demand response process, the following research can be based on the interruptible characteristics of single user, analyze the interruptible characteristics of group user cooperation and its impact on the optimal operation of power system.

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