Analysis of User Load Characteristics of Automatic Demand Response in Industrial Parks Based on Fuzzy C-means Clustering Algorithm

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Abstract. Under the background of the energy revolution of building a global energy Internet and promoting clean and green ways to meet power demand, the research on the planning and construction of smart grids and smart parks and related key technologies is becoming more and more important. This paper first introduces the automatic demand response technology of the park and the algorithm and implementation process of the load clustering technology as the basis. Secondly, the fuzzy c-means aggregation is applied to the 96-day daily load data of the 20 stations in the substation of a certain eco-city. The class algorithm performs cluster analysis, and the different load types in 5 are obtained. The demand response time interval of different load types is summarized, which provides a reference for the characteristic analysis, prediction and classification management of demand-side controllable load.

1. Introduction

The smart campus is a typical load system for building energy Internet for user terminals. The key to implementing automatic demand response technology in smart parks is to comprehensively plan user-side load and resources, study the actual curve characteristics of user load and the load response characteristics of different types of users, and implement different types of demand response schemes for different types of users. The classification of user load types can improve the security, stability and reliability of power supply in transmission and distribution networks, improve the energy efficiency of regional users, achieve safe, intelligent, energy-saving, energy-saving, environmental protection and orderly use of electricity which has become one of the new hotspots in the research of energy Internet demand response technology. It has become one of the new hotspots for researching energy Internet demand response technology.

In smart grid control and forecasting technology, some scholars combined with the new requirements of smart grid load forecasting, proposed a smart grid load forecasting platform architecture based on cloud computing platform, which made up for the shortcomings of traditional load forecasting technology in unreasonable configuration, data processing and so on [1]. Literature [2] conducted a theoretical study on the system standards and framework of power demand response. In the research of demand response technology in smart parks, the literature [3] proposes a two-way
interactive demand response strategy for daily load demand response involving multiple intelligent power solutions. In cluster research, in order to determine the number of clusters, the literature [4] proposed a clustering effective discriminant index based on FCM algorithm. Literature [5] proposed a k-means-based power load clustering analysis optimization algorithm to improve the efficiency and reliability of the output results. Chen Mingzhao, Mao Jian and other scholars applied the clustering algorithm to the demand side management of industrial users. Two types of interrupted capacity for climate-sensitive load and production load are proposed, and the corresponding DSM type is obtained [6]. In [7], considering the load curve form of power users, a power load model extraction method based on cloud model and fuzzy clustering is proposed. In [8], for the residential load containing photovoltaic and energy storage devices, a response incentive mechanism affecting the load of the civil load system and the capacity of the energy storage equipment is proposed.

In summary, at present, there is few research on using cluster analysis technology to analyze user load characteristics and then classify demand side response users. This paper will analyze the load characteristics of campus users based on clustering algorithm, and then help the development of park load forecasting and demand side response strategies.

2. Park automatic demand response architecture

The operation of the automatic demand response system requires coordinated operation of the ADR, distribution network, and user modules. The three modules rely on power equipment, transmission and distribution network, information flow, and energy flow to correlate and interact. The user module is the basis and the main object of the response; the ADR module is the “neural center system” that responds and loads the entire response system; the distribution network module is the top-level operating mechanism of the response system, responsible for the operation and promotion of the automatic demand response system. And related information collection work. In addition, some government departments play a supervisory role in this, mainly to conduct top-level supervision of distribution networks and ADR service providers and to develop relevant policy mechanisms. Figure 1 is a schematic diagram of the concept of automatic demand response:

![Figure 1. Schematic diagram of the automatic demand response concept](image-url)

This paper designs the ADR module load clustering analysis technology in the automatic demand response system. It reviews the user load data from the power consumption information collected from the gateway meter and smart terminal, and analyzes the user's load characteristics. The demand response time interval of different types of users is sent to the user module downwards; the user module is determined by the demand response time period, and the demand response is automatically performed according to the load resources in the park, thereby realizing the peaking and filling of the
power load, and achieving the matching. The effect of grid operation reliability and improving the energy efficiency level of the power system.

3. Introduction to load clustering algorithm based on fuzzy C

Clustering fuzzy algorithm is a flexible clustering method based on fuzzy partitioning. The clustering algorithm optimizes the objective function, obtains the membership degree of each sample point to all class centers, determines the class of sample points, and realizes automatic classification of sample data. At present, there are many load classification methods based on actual load curves. Fuzzy C-means clustering (FCM) algorithm performs well in terms of running time and accuracy of load clustering. It is one of the most widely used classification algorithms for electric load characteristics [5].

In the FCM algorithm, for the given data set, \( X = \{x_1, x_2, ..., x_n\} \), \( x_j \in \mathbb{R}^s \), That is, each sample in the data set is an s-dimensional vector. Divided into \( c (2 \leq c \leq n) \) classes, The vector set of each cluster center is set to \( V = \{v_1, v_2, ..., v_c\} \), The membership of each data sample \( x_j \) belonging to i-th category cluster center is \( u_{ij} \in [0,1] \), and \( \sum_{i=1}^{c} u_{ij} = 1, j = 1, 2, ..., n \). The objective function of the FCM algorithm is shown in equation (1)

\[
J(U, V) = \sum_{i=1}^{c} \sum_{j=1}^{n} u_{ij}^m d_{ij}^2
\]  

(1)

Where \( d \) is the Euclidean distance between the sample \( x_j \) and the cluster center \( v_i \). Formula is \( d = \|x_j - v_i\| \); \( m \) is a fuzzy weighting coefficient indicating the degree of blurring of the classification matrix \( U \). The calculation formulas of the membership degree \( u_{ij} \) and the cluster center \( v_i \) are as shown in equations (2) and (3):

\[
u_{ij} = \frac{1}{\sum_{y=1}^{c} (d_{ij} / d_{iy})^{m-1}}
\]  

(2)

\[
v_i = \frac{\sum_{j=1}^{n} u_{ij}^m x_j}{\sum_{j=1}^{n} u_{ij}^m}
\]  

(3)

The clustering effectiveness of FCM clustering algorithm needs to be tested to judge the rationality of the result [6], and its formula is shown in formula (4):

\[
P(U, c) = \frac{\min_{j=1}^{c} \left( \sum_{j=1}^{n} u_{ij} \right) \left( \sum_{i=1}^{c} u_{ij}^2 \right) + 1 - \sum_{j=1}^{c} \sum_{i=1}^{n} u_{ij}^2 \left\| x_i - x_j \right\|^2}{\max_{j=1}^{c} \left( \sum_{j=1}^{n} u_{ij} \right) \left[ \sum_{i=1}^{c} \sum_{j=1}^{n} u_{ij} \right] - \sum_{j=1}^{c} \sum_{i=1}^{n} u_{ij}^2 \left\| x_i - x_j \right\|^2}
\]  

(4)

Where \( x_j \in \mathbb{R}^m, i = 1, 2, ..., n \) is the m-dimensional sample vector, \( v_i \in \mathbb{R}^m, i = 1, 2, ..., c \) is the cluster center, and \( U = \{u_{ij}\} \) is the membership matrix.
4. Case analysis
This paper selects the 96-day daily load curve of 20 sets of station-level substations from July 3 to August 3, 2016 as an example to carry out FCM load clustering analysis. Due to the large difference in load levels of different stations, the extreme sequence of each typical daily load curve is standardized and preprocessed. The standardized formula is shown in equation (5).

$$x'_y = \frac{x_y}{\max[x_{11}, x_{12}, \ldots, x_{96}]}$$  \hspace{1cm} (5)

After the extreme value sequence is normalized to the typical daily load curve data calculated by the example, the value of the fuzzy weighted m needs to be determined next. The larger the fuzzy weighting coefficient m is, the fuzzier the clustering results are, and the smaller the differences among different classes in the classification results are [5], and the interval is [1, +∞]. In the literature [5], the scholars obtained from the perspective of load clustering validity, the optimal interval of m is [1.5, 2.5], and the m value is 2 when there is no special requirement.

Using FCM clustering algorithm, cluster analysis of 20 groups of station load data was carried out. When the cluster validity function $p(u,c)=0.4379$ and the number of clusters=5, the calculation is stopped, and the fuzzy clustering iteration result is output. The final load clustering results are shown below:

![Figure 2: Groups of station user daily load clustering results](image)

After clustering, the user load is divided into five categories, namely, noon peak type, late peak type, wave type, growth type and daytime peak type. Among them, the peak load of the mid-peak users is concentrated between 11:00 and 13:00; the peak load of the late-peak users lasts between 16:00 and 4:00; the fluctuation of the fluctuation users is strong, and the peak occurs at 8:00. At around 17:00, the trough appeared at 4:00 to 6:00 and around 23:00; the growth load of the growing users showed a growing trend in one day, from the low point of 4:00 to 6:00 to the peak of 19:00 and 21:00; The load peak of the type user is concentrated in the daytime between 9:00 and 19:00. The number of different types of user load and the response interval to the grid are as shown in Table 1:
Table 1. Cluster user load and response information table

| Load type  | Load characteristics | Go to the front desk | Peak clipping response period | Fillable valley response time |
|------------|----------------------|-----------------------|-------------------------------|------------------------------|
| Type 1     | Midday peak          | 2                     | 11:00 to 13:00                | 20:00 to 6:00 the next day   |
| Type 2     | Late peak type       | 4                     | 16:00 to 4:00 the next day    | 6:00 to 8:00                 |
| Type 3     | Wave type            | 2                     | 17:00 to 2:00 the next day    | 4:00 to 6:00                 |
| Type 4     | Growth type          | 8                     | 9:00 to 21:00                | 1:00 to 21:00               |
| Type 5     | Daytime peak type    | 4                     | 9:00 to 19:00                | 21:00 to 8:00 the next day   |

By clustering the above user load, the power supply side can formulate different response plans and demand side management strategies according to the load characteristics of different users and the specific types of load resources on the demand side. Therefore, users can be encouraged to participate in automatic demand response, achieve system planning and operation goals, improve the energy efficiency level of regional power users, and improve the safety and reliability of power grid operation.

5. Conclusion
In this paper, the average clustering algorithm based on fuzzy C is used to cluster and analyze the load characteristics of the automatic demand response users in intelligent parks. The load characteristics of different types of users in intelligent parks are obtained, and the load response characteristics of different types are summarized, which provides research ideas for load forecasting and control analysis of the automatic demand response users.

The results show that the FCM algorithm classifies the user load into five categories, and the five types of clustering load curves are ideal and discriminative. Different clustering results can represent the demand response of different load characteristics to the user. The research on characteristics and demand response characteristics provides effective support and can provide basis and reference for the realization of automatic demand response technology in the park.

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