Research on Modeling of Participating Entities in Demand Response System

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Abstract. Under the opened retail electricity market, the operation rules and business process of automated demand response service become more complicated. In order to deploy automatic demand respond(ADR) business, it is necessary to define the functions and operational framework of each participant in the demand response system. This paper analyzes the main participants of the demand response system, including their responsibilities, functions, behavioral models, communication architecture and logic architecture. and focuses on the modeling of demand response aggregators and power users. Moreover, the modeling of demand response aggregator and power user is emphasized.

1. Introduction

With the rapid growth of the world economy, the consumption rate of fossil energy is accelerating dramatically, and the phenomenon of imbalance between power supply and demand appears frequently0-[3]. At the same time, the problem of environmental pollution is becoming more and more serious. To tackle these problems, people proposed the conception of demand response[4]. As a novel way to balance supply and demand of electricity, consume renewable energy and promote energy saving and emission reduction, demand response has received widespread attention from all countries[5].

Demand response in China has developed for many years, forming a pattern of government-led, power grid enterprises to implement and power users' participation, and has achieved certain economic and social benefits. Automatic demand response is playing an important strategic role in power industry, energy economy development and environmental protection[6].

The implementation mechanism and process of demand response can be summarized as follows. The grid uses the advanced measurement infrastructure (AMI) to obtain the real-time load information of the user. By analyzing the state of the grid, the DR signal, including electricity price, electricity instruction suggestion, etc., is generated and transmitted to the power terminal equipment [7]. After receiving the DR signal, the terminal devices can automatically trigger the pre-set program and respond to the DR plan from grid, i.e. performing the recommended or mandatory operation[8]. After response, the users can obtain the subsidy from grid. If the user does not accept the response strategy, they can opt out freely.

The rest of this paper is organized as follows. Section 2 analyzes the communication structure and logical architecture of demand response system. The models of demand response aggregator and electricity consumer are constructed in Section 3. Then Section 4 concludes the paper.

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2. Communication and Logical Architecture of Demand Response System

The OpenADR 2.0b specification defines virtual top node (VTN) and a virtual end node (VEN) as the two roles of the communication. VTN is defined as the upstream nodes that make DR plans and transmit DR signals to other nodes such as aggregators, large industrial users and electricity markets. VEN is defined as the downstream nodes that receive and response to the DR signals. It should be noted that an entity may function as a VEN to a superordinate VTN and as a VTN to subordinate VENs[9]-[10]. The communication architecture between VTN and VEN is illustrated in Figure .

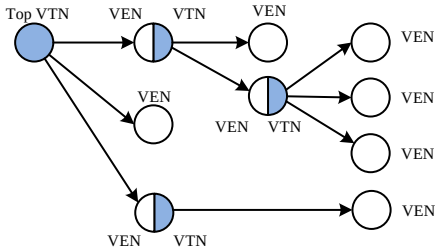

Figure 1. Communication architecture between VTN and VEN

The power demand response system has five participants, namely, power supplier, demand response service manager, demand response aggregator, demand response regulator and power user[11], the relationship between which is shown in Fig[12].

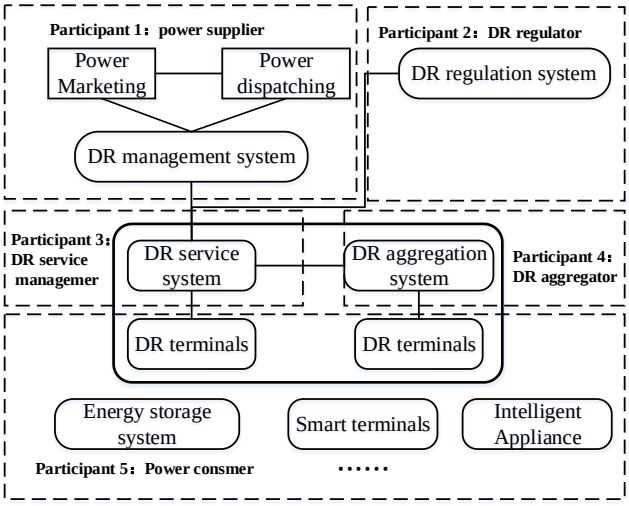

Figure 2. Relationship between five participants in DR system

The power supplier participates in the demand response through the demand response management platform, and interacts with the power users and the demand response service providers. It is responsible for releasing the dynamic price of electricity, decomposing and releasing load demand, publishing the demand response event notification, monitoring the system operation and evaluating the demand response results. Besides, it can quickly receive the feedback from the user in response to the demand and analyze the data.

The demand response aggregator participates in the demand response through the demand response aggregation system, which is connected with the demand response management platform and the demand response terminal. It is responsible for the allocation of scattered resources and the redistribution of the load reduction required by the demand response event.

The demand response service manager is responsible for managing and executing the demand response service within a region, which issues information such as electricity price, load demand and so on, and monitors the operational status of demand response system, and evaluates the effect of power users ' participation in demand response.

The demand response regulators are involved in demand response by making demand response mechanisms and rules, which include the development of requirements response plans, dynamic pricing, and demand side bidding rules.
Power users, including resident users, business users and industrial users, participate in demand response through demand response terminals, connect users' energy management systems and intelligent devices, and interact with the demand response management platform and aggregation system respectively.

3. Modeling of Demand Response Aggregator and Power Consumer

Due to the demand response aggregator and the power user are the more important entities in the demand response system, they are also the key links of DR execution, so in this section, we will analyze them in detail.

3.1. Demand Response Aggregator Modeling

Demand-response aggregators centralize power users with DR capabilities to participate as a whole in DR pilot work and act as agents for business-related matters[13]. Because the demand-response aggregator has the ability to integrate DR resources, it can be used as an active initiator of DR, a performer or only a terminal consumer with power functions. It can also act as an intermediary between the grid company and the user to promote the interaction between the supply and demand side. The main functions of the demand response aggregator can be divided into grid company setting, demand response resource management, demand response signal receiving, demand response programming, demand response signal release, power data aggregation, power data analysis and demand response evaluation, as shown in Fig.

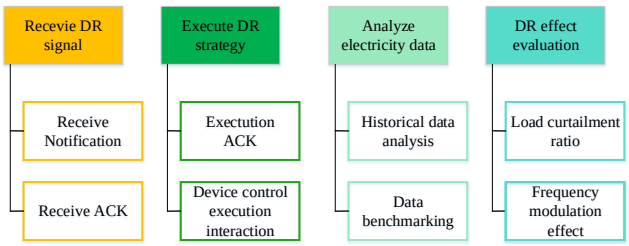

Figure 3. Functions of DR aggregator

After the DR aggregator receives the reduction metric, it needs to decompose the load and then distribute the decomposed task to the Power user. In this paper, an entropy value method is used to determine the decomposition coefficients. Entropy method is used to describe the disorder degree of a system, and when the information entropy of the index is small, the proportion of the index in the comprehensive evaluation should be greater. The calculation formula of entropy is as follows.

$$E_k(j) = -\frac{1}{\ln m}\sum_{i=1}^{m} p_{ik}(j)\ln p_{ik}(j) \tag{1}$$

$$p_{ik}(j) = s_{ik}(j) / \sum_{i=1}^{m} s_{ik}(j) \tag{2}$$

where $E_k(j)$ indicates the information entropy corresponding to power user with index k when performing the jth peak shifting task decomposition.

$$W_k(j) = [1 - E_k(j)]/[n - \sum_{k=1}^{n} E_k(j)] \tag{3}$$

where $W_k(j)$ indicates the weight of the index corresponding to the decomposition of the kth task.
In order to determine the evaluation value of each power user, it is necessary to calculate:

$$Z_i(j) = \sum_{k=1}^{n} W_k(j) \cdot y_{ik}(j) \tag{4}$$

where $Z_i(j)$ indicates that the ith user's weighted evaluation value of each index when performing the jth peak load shifting task decomposition.
Finally, we can obtain the decomposition coefficient of user *i* by equation (5).

$$R_i'(j) = Z_i(j) / \sum_{i=1}^{m} Z_i(j) \tag{5}$$

3.2. Modeling of Electricity Consumer

Power users are the carriers of power consumption and the direct participants in the implementation of DR. Since the power users are direct consumers of electricity, both and the implementation of the power demand response lunched by government, power suppliers, or power generation enterprises must rely on the power users[14]. They should update the electrical equipment of the power users and adjust the way the electricity users use electricity. Only the active participation of power consumers, could it be possible to improve the way of using electricity, improve the power efficiency of terminal, realize the reduction of installation of installed power generation and power transmission equipment, reduce power construction investment, reduce the power supply cost, saving energy resources, reduce pollutant emissions, so as to realize the overall cost of the whole society to the minimum target. Therefore, the power users are the social basis for the actual response of the power demand response, and the most important participant in the power demand response.
The power users who participate in DR can be classified into four main categories: resident user, big industry user, general industry and commerce user, the total electricity load amount of which have maintained a growth situation, while the basic structure of electricity consumption maintains stability. The biggest proportion of electricity structure is the large industrial users, the average accounted for 75%, followed by the general Industry and commerce, accounting for 13%, and finally, the resident electricity, accounting for 12%. Because of the different proportion of the power consumption of the three types of users, so is the status of participating in the implementation of DR.
As large industrial users are the biggest consumers of power loads[15], it can respond quickly to the price or incentive signals in the implementation of DR, cutting down a great deal of power demand, so it occupies a very important position in the implementation of DR. Although the electricity consumption of industrial and commercial is less than that of the industry, the general industrial and commercial load of lighting, air-conditioning load in the peak period of power system is one of the main factors affecting the power system peak load, therefore, the participation of general industrial and commercial users in DR implementation is of great significance. Resident users, including urban and rural residents, have the widest coverage and the largest number of consumers involved in electricity load. Residential users load mainly include lighting, air conditioning, washing machine, TV and other household appliances, residential electricity peak and peak power system often overlap, has an important influence on the peak load of the power system. Therefore, it is necessary to implement the residents involved in DR.
We focus on resident power users, which can be classified into five categories according to the different levels of electricity usage, whose base load lines is shown in Fig.4. Type A is vacant room users, whose electricity consumption characteristics is that the user's electricity consumption maintains a very low level, and there are no big fluctuations, the low power consumption derives from line losses. Type B users are elderly families, the electricity consumption during the day maintains a certain level, and the electricity consumption began to rise at 14:00, but the downward trend appears early. Type C is office users, whose power consumption has obvious peaks and troughs, daytime power consumption is almost equal to the night electricity consumption. Besides, evening electricity peak is later than B class, and the trend of decline is also later than Type B. Type D is office users combined with elder persons and is basically a combination of B and C. This type of user may be a mixed family of the el-

derly and the office worker. Type E is a commercial user whose power consumption has remained at a high level throughout the day.

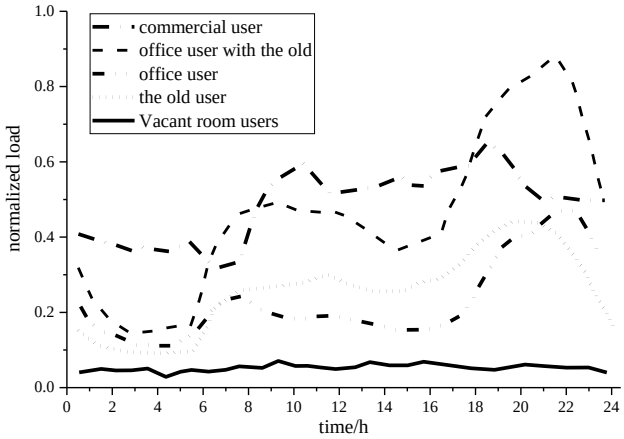

Figure 4. Different base lines of resident power users

Due to the behavior of power users is uncertain, the user's behavior is modeled according to price and incentive based demand response

1) Behavior of power users under price based DR

Based on consumer psychology model, in the death zone, price difference is small, then the user can shift electricity usage, and they may also use more electricity because the price difference is not sensitive to increased use of electricity. Therefore, the regional load transfer rate ranges in a range of positive and negative value. In the linear zone, the price difference is enough for the user to feel the pressure. At this time the transfer rate of the user is positive, but also within a certain interval distribution, and the range decreases with the increase of the price difference. In the saturated zone, the response potential has all been excavated, and the load transfer rate no longer increases with the increase of the electrical spread, but tends to be constant. This mechanism is described in Fig.5.

2) Behavior of power users under incentive based DR

Fig. 6 is the response characteristic curve of the residential users under the interruptible load(IL) scenario, and the response of the IL user is described by the rate of cut load, and the rate of cut load represents the ratio of the actual clipping load to the user's load shedding potential, i.e.

$$\lambda(x) = \sum_{i}^{n} P_{Ri}\lambda_i(x) / \sum_{i}^{n} P_{Ri} \tag{6}$$

When IL compensation level *x* reaches the *P* point, the user begins to reduce the load, but it may also do not cut its load due to low compensation. When *x* reaches the *Q* point, the user generally responds, while the cutting load rate is greater than 0, and the load reduction expected to increase, the fluctuation range is also reduced. When *x* reaches the *M* point, the user load reduction is expected to reach the maximum and the fluctuation range is approximately ignored, and all response potentials have been tapped.

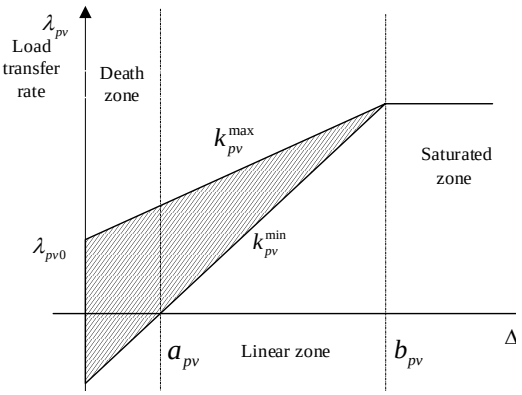

Figure 5. Behavior of power users under price based DR

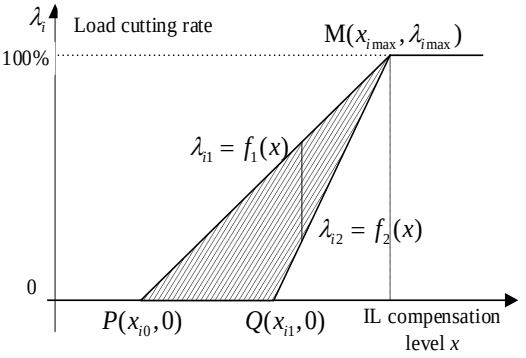

Figure 6. Behavior of power users under incentive based DR

From Fig. 6, we can conclude that under certain excitation circumstances, the user's load reduction/transfer quantity has certain randomness and thus brings certain uncertainty. And the user is driven by interest, this randomness will decrease as the level of stimulation increases. Because IL belongs to the category of non-mandatory and depend on user's voluntary response, even if the mechanism is sufficiently perfect, it will inevitably produce certain uncertainties. Thus many user agents and load-gathering operators have sprung up to provide interruptible services to reduce uncertainty through the aggregation of a large number of users.

4. Conclusion

This paper analyzes the responsibilities and functions of different participating entities in the power demand response system, as well as the cooperation mechanism and communication framework of each entity. The operation structure of demand response aggregator is analyzed emphatically, and a load decomposition strategy based on entropy method is proposed, which can be used to decompose large peak shaving task to each power user fairly and reasonably. In addition, the power consumption characteristics of several kinds of resident electricity load and the response models of power users under two scenarios, namely price based incentive based demand response, are studied. The results of this paper has certain reference meaning to the implementation of demand response.

Currently, the demand response in China is like a raging fire started, and how to use information and communication technology and mathematical modeling techniques to precisely and real-timely control the distributed load o meet the demand of the electric power market to a variety of ancillary services, is the focus of the next period of time and practical implementation challenges.

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Acknowledgments

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