A method for allocating demand response benefits considering contribution degree

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Abstract. To enhance the operational level of demand response transactions in the new power system and meet the requirements for refined management of demand response transactions, this paper proposes a novel method for allocation of demand response benefits. This method introduces the concept of contribution degree, and based on considering the contribution degree of agent users, it achieves a refined allocation of demand response benefits. This approach enables precise evaluation of agent users' participation in demand response, effectively enhancing their enthusiasm to engage in demand response, and promoting the level of market-oriented transactions in demand response. Practical applications have demonstrated the accuracy and effectiveness of this scheme in market-oriented demand response transactions.

Keyword: Contribution Degree  Benefit Distribution  Demand Response(DR)  Aggregator.

1. Introduction

In response to the dual requirements of enhancing participation in grid interactive operations and elevating the level of user-side energy efficiency, the construction of aggregators by aggregating flexible user-side resources through various demand response projects has emerged as a current research and practical focus [1]. In recent years, demand response has developed rapidly, and a comprehensive theoretical and practical system for demand response in China has been established, encompassing theoretical mechanisms, key technologies, standard specifications, and engineering applications. Considering the characteristics of load resources, which are widespread and have small individual capacities, the three-tier demand response architecture of the grid-aggregator-user agent has become the current mainstream interactive model. Aggregators aggregate and schedule various load resources from below, and interact with the grid to provide various auxiliary services from above [2]. In practice, the settlement of demand response does not focus on the response effectiveness of individual metering units, leading to insufficient precision in the responses of user agents during actual response processes. This results in issues such as excessive offer redundancy on the grid side and high incentive costs [3]. In light of this, this paper proposes a demand response benefit allocation that takes into account contribution degrees, ensuring the accurate calculation and distribution of benefits to user agents under aggregators without affecting the existing demand response evaluation and incentive system, with the aim of enhancing the quality of demand response and reducing offer redundancy.

2. Calculation of aggregated business benefit allocation

2.1 Calculation of the full benefit from aggregator demand response

The total benefit from aggregator demand response refers to the full amount of benefit derived from aggregators' participation in demand response, encompassing the benefit of the aggregator entity and the benefit of its affiliated agent users. In practical applications, the total benefit from aggregator demand response can be obtained in two ways [4].
In the first approach, the demand response platform directly calculates the total benefit of the aggregator for the current demand response, which includes the aggregator's own benefit and the benefit of all participating agent users under its jurisdiction, and sends it to the aggregator's system. The second approach involves the demand response platform calculating the benefit (including the aggregated merchant's benefit) for the participating demand response agent users and transmitting it to their respective aggregated merchant system. The aggregated merchant then adds up the benefit of all the participating agent users under its jurisdiction to obtain the total demand response benefit for the aggregated merchant.

\[ S = \sum_{j=1}^{n} (S_j) \]

Among them:
- \( S \) is the total benefit from the demand response of aggregators.
- \( S_j \) is the benefit of the \( j \)-th agent user participating in demand response, which includes the aggregated merchant's earnings.
- \( j \) is the index of the agent user, ranging from 1 to \( n \), where \( n \) is the total number of agent users participating in the demand response.

### 2.2 Ontological benefit of The demand response of aggregator

The intrinsic benefit of aggregator in response to demand refers to the benefit that they should obtain after participating in demand response, which does not include the benefit their affiliated user agents should receive[5].

The aggregate demand response benefit for the entity is typically calculated by proportionally extracting a fee from the total demand response benefit. If the extraction proportion is denoted by \( P \) (typically ranging from 0 to 20%), then the single demand response benefit for the entity by the aggregator is given by:

\[ I_{agg} = S \times P \]

Among them:
- \( I_{agg} \) is the ontological Gain of The demand response of aggregators.
- \( S \) is the total benefit from demand response by aggregators.
- \( P \) is the proportion of benefit extraction by the aggregator participating in demand response.

### 3. The calculation of agent user benefit allocation

#### 3.1 The total benefit of all agent users

The total benefit of all agent users refers to the aggregate total benefit of all participating agent users under the jurisdiction of the aggregator, excluding the intrinsic benefit from the aggregator's demand response. This benefit can be derived by subtracting the intrinsic benefit of the aggregator's single demand response from the full benefit from the aggregator's demand response. Its calculation method is as follows:

\[ I_{agent} = S - I_{agg} \quad \text{or} \quad I_{agent} = S \times (1-P) \]

Among them:
- \( I_{agent} \) is the total benefit generated by all agent users
- \( S \) is the total benefit generated from this demand response
- \( I_{agg} \) is the intrinsic benefits of this demand response for the aggregator
- \( P \) is the proportion of benefit extraction by aggregators participating in demand response

#### 3.2 Benefit of the measurement unit

#### 3.2.1 Contribution of benefit to each measurement unit

Assuming that the execution duration of a demand response is \( T \) minutes and the duration of a metering unit for the demand response is \( t \) minutes, the number of metering units \( m \) for this
demand response can be calculated by dividing the execution duration by the duration of the metering unit, as follows:

\[ m = \frac{T}{t} \]

Assuming the overall declared response volume for the demand response by the aggregator is \( R \), the baseline load for the i-th metering unit is \( G_i \), and the actual load for the i-th metering unit is \( L_i \), then the actual response volume for the i-th metering unit is \( (RS)_i = L_i - G_i \) (here, taking the peak-cut demand response as an example, with \( i \) ranging from 1 to \( m \)).

The actual response quantity \( (RS)_i \) of each metering unit is divided by the declared response quantity \( R \), resulting in the response proportion \( K_i \) of the i-th metering unit. That is:

\[ K_i = \frac{(RS)_i}{R} \]

Based on the value of \( K_i \), the corresponding benefit coefficient \( B_i \) for the i-th metering unit is obtained by consulting the K-value benefit coefficient table. Here, we take the demand response benefit coefficient table for a specific province as an example.

<table>
<thead>
<tr>
<th>The value of ( K )</th>
<th>The coefficient of Benefit</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;60%</td>
<td>0</td>
</tr>
<tr>
<td>60%,80%</td>
<td>0.6</td>
</tr>
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<td>90,120%</td>
<td>1</td>
</tr>
<tr>
<td>&gt;120%</td>
<td>the amount Exceeding 120% yields no benefit</td>
</tr>
</tbody>
</table>

![Figure 1: Table of Benefit Coefficient for DR K-value in a Certain Province](image)

The sum of the benefit coefficients, \( B \), is equal to the sum of the benefit coefficients of all metering unit, calculated as follows:

\[ B = \sum_{i=1}^{m} (B_i) \]

Among them:

- \( B \) is the sum of the coefficients of benefit
- \( B_i \) is the benefit coefficient for each unit of measurement
- \( i \) is the index of measurement units, from 1 to \( m \), where \( m \) is the number of measurement units in demand response.

The contribution of the i-th measurement unit to the overall benefit is determined by dividing its benefit coefficient by the total sum of all benefit coefficients, as follows:

\[ Pro_i = \frac{B_i}{B} \]

Among them:

- \( Pro_i \) is the contribution degree of the i-th measurement units to the benefit.
- \( B \) is the sum of the coefficients of benefit.
- \( B_i \) is the benefit coefficient for the i-th unit of measurement.
- \( i \) is the index of measurement units, from 1 to \( m \), where \( m \) is the number of measurement units in demand response.
- \( j \) is the index of the agent users, ranging from 1 to \( n \), where \( n \) is the total number of agent users participating in the demand response.

3.2.2 The total benefit metering unit

The total benefit of the i-th measurement unit is equal to the benefit contribution of the i-th measurement unit multiplied by the total benefit of all agent users, calculated as follows:

\[ I_i = Pro_i \times I_{agent} \]

Among them:

- \( I_i \) is the total benefit of the i-th measurement unit.
The value of $K$ is Contribution of the $i$-th measurement unit to the benefitability.

$I_{\text{agent}}$ is the total benefit amount of all agent users.

$i$ is the index of measurement units, from 1 to $m$, where $m$ is the number of measurement units in demand response.

### 3.3 The unit point total benefit of the agent user

Let the declared response volume of the $j$-th agent user under the jurisdiction of the aggregator be denoted as $R_j$. The baseline load of the $i$-th metering unit for the $j$-th agent user is $(G_j)_i$, while the actual load of the $i$-th metering unit for the $j$-th agent user is $(L_j)_i$. The actual response volume of the $j$-th agent user for the $i$-th metering unit $(RS)_i = (L_j)_i - (G_j)_i$ (here, taking the peak shaving demand response as an example, $j$ ranges from 1 to $n$, where $n$ represents the number of agent users participating in this demand response by the aggregator, and $i$ ranges from 1 to $m$, where $m$ represents the number of metering units involved in the demand response).

The response proportion $(K_j)_i$ of the $i$-th metering unit for the $j$-th agent user is equal to the actual response amount $(RS)_i$ divided by the declared response amount $R_j$ of the $j$-th agent user, with the calculation formula as follows:

$$(K_j)_i = (RS)_i / R_j$$

Among them:

- $(K_j)_i$ is the response proportion of the $i$-th metering unit for the $j$-th agent user
- $(RS)_i$ is the actual response quantity of the $i$-th metering unit for the $j$-th agent user
- $R_j$ is the response volume reported by the $j$-th agent user
- $i$ is the index of measurement units, from 1 to $m$, where $m$ is the number of measurement units in demand response.

$j$ is the index of the agent users, ranging from 1 to $n$, where $n$ is the total number of agent users participating in the demand response.

Based on the value of $(K_j)_i$, check the K-value benefit coefficient table to obtain the corresponding benefit coefficient $(B_j)_i$, where $(B_j)_i$ refers to the benefit coefficient of the $j$-th agent user at the $i$-th measurement unit. Taking the K-value benefit coefficient table of a certain province's demand response as an example.

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Figure 2 Table of Benefit Coefficient for DR K-value in a Certain Province

The sum of the benefit coefficients at the $i$-th measurement unit is equal to the sum of the benefit coefficients of all agent users at that measurement unit. The calculation method is:

$$B_i = \sum_{j=1}^{n} (B_j)_i$$

Among them:

- $B_i$ is the sum of the benefit coefficients of the $i$-th measurement unit.
- $(B_j)_i$ is the benefit coefficient of the $j$-th agent user at the $i$-th unit.
- $i$ is the index of measurement units, from 1 to $m$, where $m$ is the number of measurement units in demand response.
- $j$ is the index of the agent users, ranging from 1 to $n$, where $n$ is the total number of agent users.
participating in the demand response.

The benefit contribution of the j-th agent user at the i-th measurement unit is the sum of the benefit coefficient of the agent user at the i-th measurement unit divided by the benefit coefficient of the i-th measurement unit. The calculation formula is:

\[(\text{Pro}_j)_i = \frac{(B_i)_j}{(B)_i}\]

Among them:

- \((\text{Pro}_j)_i\) is the contribution of the j-th agent user's benefit at the i-th measurement unit.
- \((B_i)_j\) is the benefit coefficient of the j-th agent user at the i-th measurement unit.
- \((B)_i\) is the total benefit coefficient of the i-th measurement unit.
- \(i\) is the index of measurement units, from 1 to m, where m is the number of measurement units in demand response.
- \(j\) is the index of the agent users, ranging from 1 to n, where n is the total number of agent users participating in the demand response.

The benefit amount of the j-th agent user at the i-th measurement unit is calculated by multiplying the benefit contribution of the j-th agent user at the i-th measurement unit by the total benefit amount at the i-th measurement unit. The calculation formula is:

\[(I_i)_j = I_i * (\text{Pro}_j)_i\]

Among them:

- \((I_i)_j\) is the benefit of the j-th agent user at the i-th measurement unit.
- \(I_i\) is the total benefit of the i-th measurement unit.
- \((\text{Pro}_j)_i\) is the benefit contribution of the j-th agent user at the i-th measurement unit.
- \(i\) is the index of measurement units, from 1 to m, where m is the number of measurement units in demand response.
- \(j\) is the index of the agent users, ranging from 1 to n, where n is the total number of agent users participating in the demand response.

### 3.4 The benefit of Agent user in demand response

The demand response benefit of the j-th agent user is the cumulative benefit of each measurement unit of the agent user, and the calculation formula is:

\[I_j = \sum_{i=1}^{m} (I_i)_j\]

Among them:

- \((I_i)_j\) is the benefit of the j-th agent user at the i-th measurement unit.
- \(I_j\) is the demand response benefit of the j-th agent user.
- \(i\) is the index of measurement units, from 1 to m, where m is the number of measurement units in demand response.
- \(j\) is the index of the agent users, ranging from 1 to n, where n is the total number of agent users participating in the demand response.

### 4. Demonstration application

The demand response allocation method designed in this article, which takes into account contribution, supports the benefit allocation and settlement service under the demand response business of the new power load management system. By accurately calculating the contribution of agent users, the benefit can be fairly distributed, meeting the fairness principle of market-oriented transactions in power demand response business.

The demand response benefit distribution method designed in this article, which takes into account contribution, is applied as a demonstration in Ningxia and other provinces, regions, and cities. It is used by power companies to carry out benefit distribution and settlement work in power
demand response, effectively supporting the development of demand response benefit distribution and settlement business in the new power load management system, improving the fairness of market-oriented transactions, promoting the participation enthusiasm of agent users, and receiving unanimous praise from aggregators and agent users.

5. Summary

The demand response benefit distribution method designed in this article, which takes into account contribution, has been continuously and stably running in the new power load management system since its trial operation, meeting the business needs of multiple entities such as the marketing department of the provincial power company, the provincial marketing service center, the load management specialist of the municipal power supply company, the key account manager, and the agent, proving the feasibility of the design [6]. The drawback of this algorithm is that it requires a linear proportional relationship between contribution and benefit coefficient. When contribution and benefit coefficient are not linearly proportional, the fairness of this algorithm will decrease. In the future, we will further study and improve the optimization algorithm to meet the needs of actual business [7][8].

Acknowledgments

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