Quantitative research on the contribution of demand-side response to the promotion of renewable energy consumption

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Abstract. Current demand side resources gradually become an important part of promoting renewable energy given, using price, taxes, subsidies and other economic mechanism, encourage users to change electricity behavior, complete with the maximization of expected load curve fitting, to achieve the peak cut, or peak adjustment, to maximize the utilization of renewable energy power generation. Based on the reasonable classification and definition of user types and demand-side resources, this paper constructs a grid load influence degree model of compatible demand-side resources, and quantitatively studies the contribution degree of demand-side response to promoting renewable energy consumption.

1. Introduction
Demand response (DR) and renewable energy (RES) have good complementary characteristics. The participation of demand-side resources is increasingly important to improve the system's absorption of renewable energy, which is expected to become a new way to adjust load and adapt to the development of power grid.

Literature proposes a phased implementation model of demand-side management for large-scale wind power grid connection, focusing on the application research of DR project types. The implementation of demand response is closely related to the current situation and reform process of electricity market. Introducing demand response in market competition and enhancing the role of demand-side resources in the market through price signals and incentive mechanism is an inevitable requirement to adapt to the development of the electricity market.

Based on the quantitative research of demand-side response promoting renewable energy consumption, this paper firstly defines the user type and its demand-side resources, then constructs the grid load influence degree model of compatible demand-side resources, and finally selects the data of each power supply region of H province for example analysis, and obtains relevant research conclusions.

2. Definition of user types and demand-side resources

2.1. Demand-side resource classification

2.1.1. Energy efficiency resources. Energy efficiency resources refer to the technical measures to reduce the amount and load of electricity by improving the efficiency of electricity consumption. The introduction of energy-efficiency resources can reduce the amount of electricity consumed by users all
the time, thus reducing their demand for generation capacity and transmission capacity. Energy efficiency resources reduce the amount of electricity by improving the efficiency of electricity consumption, but do not change the level of electricity service.

2.1.2. Load resources. Load resources are economic or administrative measures to reduce the peak load of the system through the voluntary response of users to reduce the power consumption of electrical equipment or change the time of electricity consumption. Load resources can reduce part of the power load during the peak period of the system, that is, transfer from the peak period to the trough period, so as to improve the reliability level of the system power supply.

2.2. User types and demand-side resources
There are various types of power terminal users, and different types of power users have different demand-side resources. In order to carry out load forecasting more accurately and analyze the effect of various demand-side resources on power users, each user should first make clear his own user type and demand-side resources. After each user category is divided, the potential energy efficiency resources and load resources of each user category are determined.

3. Establishment of network load influence degree model of compatible demander resources
(1) Determine the scope of the forecast. (2) Classify the users. (3) Identify the various demand-side resources of various users. (4) Quantitative analysis of the impact of various users and various demand-side resources on the load during the forecast period. (5) The maximum load of demand-side resources in the forecast area can be calculated by multi-level superposition technology.

The general idea of this method is shown in the figure below:

![Diagram](image.png)

Figure 1. The general train of thought of load forecasting method compatible with demand side resources

3.1. Consider the maximum load analysis under the action of multiple demand-side resources
Based on the above analysis, this part focuses on the load forecasting model compatible with demand-side resources.

Before analyzing and predicting the effect of electricity saving under the action of demand-side resources, it is necessary to first calculate the predicted annual electricity consumption without considering the action of demand-side resources, as shown in Formula (1), (2):

\[ Q_{0,\text{pre}} = Q_0 \cdot (1 + N \cdot T) \]  

\[ P_{0,\text{pre}} = \frac{Q_{0,\text{pre}}}{\beta_0 t} \]  

Type, \( Q_{0,\text{pre}} \) represents the electricity consumption of demander resources in the forecast year, kWh; \( Q_0 \) is the initial power consumption, kWh; \( N \) is the annual average growth rate of electricity consumption; \( T \) is the number of years from the beginning to the predicted year, years; \( P_{0,\text{pre}} \) represents the predicted maximum load of the year without considering the demand side resources, kW; \( \beta_0 \) is the initial load rate (kW); \( t \) is the number of hours in the forecast period, hours.
3.2. Consider the maximum load forecast of various demander resources
This section is extended on the basis of considering the case of a single demand-side resource, considering the maximum load forecast of multiple demand-side resources.

3.2.1. Analysis of various energy efficiency resources. Assume that $\Delta Q$ for saving electricity quantity, $\Delta Q_i$ said the ith a link the amount of electricity saving electricity, $Q_{i,0}$ means in the case of a power link $i$ predict initial electricity consumption, $\alpha_{EE,i}$ for the user the ith a link under the action of the resource of energy efficiency on electricity consumption rate, $\lambda_i$ indicates whether the resource of energy efficiency coefficient of state of being, when the $\lambda_i$ value of 0, users do not have these resources; When the value is 1, the resource is available.

Under the effect of energy efficiency resources, the power saving amount in the second power consumption link of this type of user can be expressed as:

$$\Delta Q = Q_{i,0} \cdot \lambda_i \cdot \alpha_{EE,i}$$

(3)

Under the action of a variety of energy efficiency resources, the total power saving amount is the sum of the power saving amount of each link, namely

$$\Delta Q = \Delta Q_1 + \Delta Q_2 + \cdots + \Delta Q_k$$

(4)

Where, $k$ represents the number of links used by the power user.

Therefore, the electricity consumption under the action of energy efficiency resources $Q_{EE}$ is:

$$Q_{EE} = Q_{0,pre} - \Delta Q$$

(5)

3.2.2. Multiple load resource analysis. The calculation formula of the maximum load reduced under the action of a single load resource is as follows:

$$\Delta P_{\text{max},i} = \begin{cases} P_{\text{max},EE} \cdot Q_{EE} \cdot \frac{1}{\beta_{LD,i}} \cdot \frac{1}{t} & \lambda_i = 1 \\ 0 & \lambda_i = 0 \end{cases}$$

(6)

$$P_{\text{max},EE} = \frac{Q_{EE}}{\beta_0 \cdot t}$$

(7)

Where, $\Delta P_{\text{max},i}$ represents the maximum load reduced under the action of resource of the ith load class, kW; $P_{\text{max},EE}$ represents the maximum load under the action of energy efficiency resources, kW; $\beta_{LD,i}$ is the load rate under the action of the ith load resource of the power user.

Therefore, the prediction results of the maximum load under the action of demand-side resources are as follows:

$$P_{\text{max}, DSM} = P_{\text{max},EE} - \Delta P_{\text{max}}$$

(8)

3.3. Solving the maximum load of multiple power users in the same area
Assuming that $P_{\text{max},ij}$ is the maximum load of class $j$ power users in region $i$ under the action of demand-side resources, then the superposition result of benefits of all users in region $i$ is:

$$P_{\text{max},i} = \left( \sum_{j=1}^{m} P_{\text{max},ij} \right) \cdot \bar{\zeta}_2$$

(9)

Where, $m$ represents the number of classified power users; $P_{\text{max},i}$ is the maximum load in the i region, kW; $\bar{\zeta}_2$ represents the load coincident rate and is used to adjust the maximum load between different users in the same area.

4. Example analysis
In this section, the power supply regions in H province are analyzed to calculate the effect of power saving and charge reduction under the action of energy efficiency resources and load resources, and
the relevant results are analyzed and compared to compare the changes of renewable energy consumption before and after the addition of demand-side response.

Combined with the basic data and parameters of the assignment, use of compatible demand side resources, a new method of maximum load forecasting, demand side resources under the maximum load $= \text{no account of demand side resources under load} \times (1 - \text{energy-saving potential value}) \times \text{under the action of load rate} \times \text{load resource rate at the same time}$, specific as shown in table 3:

Table 1. Maximum load forecast for demand-side resources

| The user types       | The forecast period does not take into account the maximum load of demander resources (MW) | Maximum load under demand-side resources (MW) | Maximum load reduction under demand-side resources (MW) | Maximum load reduction ratio (%) |
|----------------------|-----------------------------------------------------------------------------------------------|-----------------------------------------------|--------------------------------------------------------|---------------------------------|
| Residents            | 6428.05                                                                                     | 5127.66                                       | 1300.39                                                | 20.23%                          |
| light industry       | 619.64                                                                                      | 504.51                                        | 115.13                                                 | 18.58%                          |
| heavy industry       | 2595.89                                                                                     | 2096.70                                       | 499.19                                                 | 19.23%                          |
| The hotel            | 965.56                                                                                      | 844.29                                        | 121.27                                                 | 12.56%                          |
| The mall             | 1221.24                                                                                    | 1102.05                                       | 119.19                                                 | 9.76%                           |
| Office buildings     | 938.49                                                                                      | 818.55                                        | 119.94                                                 | 12.78%                          |
| Research institutions| 658.75                                                                                      | 544.59                                        | 114.16                                                 | 17.33%                          |
| Organ                | 1061.82                                                                                    | 899.15                                        | 162.67                                                 | 15.32%                          |
| Hospital             | 965.56                                                                                    | 915.16                                        | 50.40                                                  | 5.22%                           |

Table 2. Statistical table of thermal power and renewable energy consumption before and after the introduction of demand-side resources

| Renewable energy consumption (MW) | Before introduction of demand-side resources | After introducing demand-side resources |
|-----------------------------------|---------------------------------------------|----------------------------------------|
| average value                     | 2147.39                                     | 2825.68                                |
| maximum value                     | 3292.09                                     | 3533.40                                |
| minimum value                     | 560.56                                      | 1776.14                                |
| Thermal power (MW)                | Before the introduction of demand-side resources | After introducing demand-side resources |
| Minimum reserve on thermal power  | 1158.00                                     | 1225.61                                |
| Minimum standby value under thermal power | 83.84                                      | 584.54                                  |
| Variance of thermal power output  | 997.61                                      | 680.67                                  |

5. Conclusion
After example analysis, for the thermal power unit output change and renewable energy consumption after the introduction of demand-side resource response, the following conclusions are drawn:
Demand-side response has a significant effect on the reduction of the maximum load of the power grid, and plays an optimized role in the stable absorption of renewable energy.

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