The sales aspect of electricity reform is one of the focuses of current reform in China. Independent retailers are involved in the purchase of electricity, which is a sign of a mature electricity market. With the increasing degree of market opening, it is expected to become an important link between the generation side and demand side, and its degree of participation will directly affect the benefits of the demand response. From the analysis of the operation pattern of future electricity retailers that are involved in optimal generation dispatching, the load-calculation model of the customer response and the dispatching model of electricity retailers involved in generation are established. Then, based on the principle of dynamics, a comprehensive assessment model is established. The results show that customers' response to electricity retailers involved in the generation dispatch can improve the load rate by about 4%. The overall efficiency of various stakeholders is positive, and the investment cost of the government environmental management is gradually decreased.

1. Introduction

Since the release of the “No. 9 Document” in 2015 in China, some supporting documents have also been introduced, which indicates that electricity reform in China has reached an important stage [1]. For the electricity reform on the demand side, the main content is to open the electricity sale market and to set up independent electricity retailers to facilitate the direct trade between the demand side and generation side. Therefore, electricity retailers have become an important link between producers and customers, which provides a good market environment for electricity retailers involved in optimal generation dispatching [2, 3].

The influence of the opening degree of the demand side on the electricity retailers is clear. As the opening degree increases, the market share is greater in that electricity retailers could participate, and there is an influence on the generation dispatching. According to the most recent reports, it is expected that there will be full liberalization of industrial land by the end of 2018, and by the end of 2020, there will be full liberalization of commercial land. This clearly speeds up the pace at which the demand increases, increasing chips for the influence of electricity retailers participating in generation dispatching [4, 5].

At present, although some scholars have researched aspects of the problems related to the electricity market after the establishment of electricity retailers in China, there are few studies about the influence on the generation side after the establishment of electricity retailers [6, 7]. With respect to the modelling of DR (Demand Response), Mahmoudi N [8] modeled different types of demand response resources in the Australian electricity market, including long-term resources, real-time resources, spot-market resources, peak price resources, long-term contract market resources, and price returns resources. It also models how retailers purchase different types of demand response resources from load aggregators, as well as establishes an electricity-purchasing strategy model that considers the contract price and user participation. Li Z [9] considers the users' participation in terms of the demand response during peak periods and uses the load-price curve to establish the utility model of customers, thereby maximizing the utility of customers and achieving the goal of optimizing the network operating cost during the peak period. Zhang C [10] further classifies the
user loads that can participate in the demand response and divides them into nonelastic loads and elastic loads. Elastic loads are further divided into load reduction and transferable loads, and, on this basis, a mathematics-based approach is established. The model proposes a purchase and sale electricity model that combines customer load aggregators.

However, based on the present situation with respect to the deepening of electricity reform as well as current problems that exist in power-grid operation, there is an urgent need to research electricity retailers involved in generation dispatching [11, 12]. This paper proposes a model of generation dispatching considering the participation of electricity retailers and the response of customers. Moreover, based on the analysis investigating the market behavior of customers, electricity retailers, and producers, the paper studies the comprehensive benefits of various stakeholders and provides theoretical support for electricity retailers involved in the dispatch of optimal generation dispatching.

2. Materials and Methods

2.1. Analysis on Operation Pattern of Electricity Retailers.

According to the electricity reform framework in the No.9 Document, it is necessary to release the demand side and generation side and to control the power grid. Combined with the practice of electricity market construction in different countries, as well as the positions and features of electricity retailers in the operation pattern, this paper proposes the operation pattern of electricity retailers using a price-based demand response, as shown in Figure 1.

From Figure 1, the DR of a buyer refers to general electricity customers [13]. During peak periods, the buyer can reduce the peak load by reducing the electricity demand and realize a demand response according to the reduced load. In addition, the DR of a seller refers to the electricity customers with supply capacity, including distributed power and electric vehicles [14]. During peak periods, the seller can increase the peak response capacity of the power grid by increasing their power supply and can realize the demand response according to the supplied power.

Electricity retailers are the critical connect between customers and generation companies. The function of electricity retailers in an operation pattern is equivalent to those of aggregation service providers. Generation companies propose a load-reduction plan or electricity supply plan during the peak period, and electricity retailers integrate these plans and issue a demand response plan to customers, after which they conduct settlement evaluation in accordance with the final response degree of customers.

2.2. Customer Response Load-Calculation Model.

Four types of load-calculation model were analyzed for cases where customers participated in demand response, including industrial, commercial, and residential customers and electric vehicles [15, 16]. According to the classification, industrial and commercial customers belong to the DR of buyer resources, and residential customers and electric vehicles both belong to the DR of seller and buyer resources.

According to the analysis on the operation pattern of electricity retailers, generation companies publish a load-reduction plan, and electricity retailers change customers’ electricity modes by employing price or incentive measures [17, 18]. As the load-reduction plan is completed, the reserve capacity on the generation side as well as the costs of start-up and shutdown are reduced, and then the generating efficiency is increased. First, according to the customer demand response used to calculate the load, the assumptions of the specific model are as follows.

(1) The typical daily load curve has two peak periods and a valley period; there are two peak prices and one valley price.
(2) There are upper limits on the adjustable power for different customers, and among them, the residential adjustable power factor is the minimum, and the electric vehicle is the maximum.

(3) Compensation should be given to customers who reduce their loads during the peak period, and it is based on the principle of contribution, regardless of the customer category.

The demand response analysis only considers the peak load reduction of various customers according to their adjustable usage of electricity, after electric vehicle retailers break down their load-reduction plan. Before responding to the load reduction of various customers according to their vehicle is the maximum.

Adjustable power factor is the minimum, and the electric vehicle is considered as a load reduction.

Thus, the load-change status of various customers during the peak period can be calculated, and the calculation model is as follows.

\[
c_i = \int_0^{t_1} L_a \cdot p_{ig} \, dt + \int_{t_1}^{t_2} L_{it} \cdot p_{if} \, dt + \int_{t_2}^{t_3} L_{it} \cdot p_{ip} \, dt + \int_{t_3}^{t_4} L_a \cdot p_{ig} \, dt
\]

\[
+ \int_{t_4}^{24} L_a \cdot p_{ig} \, dt + \int_{t_4}^{24} L_{it} \cdot p_{ip} \, dt
\]

where \( c_i \) is the electricity cost for the category \( i \) of customers, when \( i = 1 \) represents electric vehicles, \( i = 2 \) represents industrial customers, \( i = 3 \) represents commercial customers, and \( i = 4 \) represents residential customers. \( t_i \) shows the nodes during different periods, where \( 0 - t_1 \) and \( t_1 - t_2 \) and \( t_2 - t_3 \) and \( t_3 - t_4 \) are the peak period, and others are the flat period. \( L_i \) is the load of category \( i \) of customers in time \( t \); \( p_{if} \) is peak price of category \( i \) of customers, \( p_{ip} \) is the flat price of category \( i \) of customers, and \( p_{ig} \) is the valley price of category \( i \) of customers.

Assuming that the total load-reduction plan is \( Q_p \), shared by the reduced load of all kinds of customers, define \( Q_p \), and shared by the supply load of electric vehicles, define \( Q_p^v \). The cost-calculation model of various customers responding to the incentive mechanism is as follows.

\[
c^v_i = \int_0^{t_1} L^v_a \cdot p_{ig} \, dt + \int_{t_1}^{t_2} L^v_{it} \cdot p_{if} \, dt + \int_{t_2}^{t_3} L^v_{it} \cdot p_{ip} \, dt + \int_{t_3}^{t_4} L^v_a \cdot p_{ig} \, dt
\]

\[
+ \int_{t_4}^{24} L^v_a \cdot p_{ig} \, dt + \int_{t_4}^{24} L^v_{it} \cdot p_{ip} \, dt
\]

where \( c^v_i \) is the electricity cost of the category \( i \) of customers after the response and \( L^v_{it} \) is the load function of the category \( i \) of customers at time \( t \) after the response.

Thus, the load-change status of various customers during the peak period can be calculated, and the calculation model is as follows.

\[
\Delta Q_{if} = \int_{t_1}^{t_2} (L_{it} - L^v_{it}) \, dt + \int_{t_2}^{t_3} (L_{it} - L^v_{it}) \, dt
\]

where \( \Delta Q_{if} \) is the load reduction of the category \( i \) of customers during the peak period. For electric vehicles, which can charge and discharge, the discharge of electricity corresponds to the reduced charge of electricity, so it is all considered as a load reduction.

\[
\Delta Q_{ig} = \int_{t_1}^{t_2} (L^v_{it} - L_a) \, dt + \int_{t_2}^{t_3} (L^v_{it} - L_{it}) \, dt
\]

where \( \Delta Q_{ig} \) is the load increase of the category \( i \) of customers in the valley period. Considering the reduced electricity consumption of some customers, it will be supplemented during the valley period.

\[
\Delta Q_{if} + \Delta Q_{ig} \leq Q^v_i
\]

where \( Q^v_i \) is the upper limit of the variable electricity of customers. The upper limit is related to customer characteristics, and \( \theta_i \) is a variable. The calculation model of the variable electricity upper limit of various customers is as follows.

\[
Q^v_i = \int_0^{24} L_a \, \theta_i
\]

For the incentive mechanism, subsidies are given to customers who reduce power consumption during the peak period. Assume that there is a fixed maximum subsidy that can be provided by electric retailers, defined as \( A_T \). The subsidy of various customers is given as follows.

\[
A_i = A_T \cdot \frac{\Delta Q_{if} + \Delta Q_{ig}}{\sum_{i=1}^{4} (\Delta Q_{if} + \Delta Q_{ig})}
\]

where \( A_i \) represents subsidies of the category \( i \) of customers.

Thus, it should consider the subsidies when calculating the electricity cost after the response, which is given as follows.

\[
c^v_i = c^a_i - \alpha \cdot \Delta Q_{if} + p_{ig} \cdot \Delta Q_{ig}
\]

where \( c^a_i \) is the electricity cost of category \( i \) of customers after considering the subsidies; \( \alpha \) is the unit cost of subsidies of the peak load.

\[
\alpha \cdot \sum_{i=1}^{4} \Delta Q_{if} \leq A_T
\]

2.3. Generation Dispatch Model. The generation side will be affected by the implementation of the response policy on the demand side, including the load reduction during the peak period and the load increase during the valley period. Assume that there are \( n \) peak adjusting reserve units in total. Before the implementation of the demand response policy, these units operate during peak time, and the coal consumption rate of the start-up and shutdown is higher than that in normal time. The calculation model to determine the coal consumption cost of peak adjusting units before the demand response is given as follows.

\[
c_{it} = \xi \cdot \sum_{i=1}^{4} \left( \int_{t_1}^{t_2} L_{it} \, dt + \int_{t_2}^{t_3} L_{it} \, dt \right) \cdot c_c + y \cdot n \cdot c_c
\]

where \( c_{it} \) is the generation coal consumption cost of reserve units, \( \xi \) is the unit power coal consumption rate during normal operation time, \( c_c \) is the unit coal cost, and \( y \) is the coal consumption rate during the start-up and shutdown times.
After the implementation of the load-reduction plan, the peak load is reduced, and the number of reserve units that needs to be started decreases. Then, the calculation formula to determine the coal consumption cost of reserve units is given as follows.

\[ c^u = \xi \cdot \sum_{i=1}^{4} \left( \int_{t_1}^{t_2} L^a d_t + \int_{t_3}^{t_4} L^a d_t \right) \cdot c_c + \gamma \cdot n_j \cdot c_e \]  \hspace{1cm} (11)

where \( c^u \) is the coal consumption cost of reserve units after the response, and \( n_j \) is the number of units for peak adjusting after the response.

\[ \Delta c_{at} = \left[ \xi \cdot \sum_{i=1}^{4} \Delta Q_{ij} - \gamma \cdot n_k \right] \cdot c_c \]  \hspace{1cm} (12)

where \( \Delta c_{at} \) is the cost fluctuation of reserve units during the peak period.

For the increased electricity demand during the valley period, the corresponding number of units that need to be shut down is reduced, leading to a reduced unit cost. The calculation formula of the coal consumption cost fluctuation during the valley time is shown as follows.

\[ \Delta c_{gy} = \left[ \xi \cdot \sum_{i=1}^{4} \Delta Q_{iy} - \gamma \cdot n_k \right] \cdot c_c \]  \hspace{1cm} (13)

where \( \Delta c_{gy} \) is the variable cost of the coal consumption during the valley period and \( n_k \) is the reduced number of units that needs to be shut down.

Thus, we can calculate the change in the total revenue on the generation side, which is calculated as follows.

\[ \Delta \pi_p = p_o \cdot \sum_{i=1}^{4} \left( \Delta Q_{ij} - \Delta Q_{if} \right) - \Delta c_{at} - \Delta c_{gy} \]  \hspace{1cm} (14)

For electricity retailers, before the response to the load-reduction plan, the formula to determine their income of them is as follows.

\[ \pi_s = \sum_{i=1}^{4} c_i \cdot (p_o + p_l) \cdot \sum_{i=1}^{4} \int_{0}^{24} L^a d_t \]  \hspace{1cm} (15)

where \( \pi_s \) is the income of electricity retailers before the demand response and \( p_l \) is the transmission and distribution price. After the implementation of the load-reduction plan, the income of the electricity retailers is determined as follows.

\[ \pi_s^a = \sum_{i=1}^{4} c_i^a - (p_o + p_l) \cdot \sum_{i=1}^{4} \int_{0}^{24} (L^a - L^u) d_t - A_T + \varepsilon \]  \hspace{1cm} (16)

where \( \pi_s^a \) is the income function after the demand response of electricity retailers and \( \varepsilon \) is the government subsidy.

From this, the income change formula of electricity retailers before and after the response to the load-reduction plan is as follows.

\[ \Delta \pi_s = \sum_{i=1}^{4} \left( c_i^a - c_i \right) - (p_o + p_l) \cdot \sum_{i=1}^{4} \int_{0}^{24} (L^a - L^u) d_t \]  \hspace{1cm} (17)

\[ - A_T + \varepsilon \]

### 2.4. Comprehensive Benefit Assessment Model

#### 2.4.1. Simulation Ideas

The implementation of the demand response can be classified as a price demand response and an incentive demand response. At the beginning of the implementation, owing to the investment of government subsidies, some categories of customers will actively participate. A reduction or transfer of the load will result in a significant decrease in the systemic peak load, and the load rate will increase. Meanwhile, it also enables access to distributed power and the use of electric vehicles. As the government subsidizes customers and electricity retailers, the costs are correspondingly reduced. Various stakeholders benefit from the demand response project, thereby leading to an increased input into demand response projects. Customers may choose to enter or exit the project at will, and electricity retailers may choose to continue or reduce their investment based on the benefits of the demand response. If the government increases the subsidy, the electricity retailers will increase the input of the demand response, but because of the limitations of the customers’ adjustable power, once it exceeds a certain range, it will have negative effects. When the efficiency of the increased investment is poor, government will reduce the subsidy, and this cyclic process constitutes the basis for the establishment of a dynamic model [19, 20]. The specific simulation schematic is shown in Figure 2.

#### 2.4.2. Causal Circuit Diagram

According to the simulation schematic diagram, the causal relationship between the various elements in the system is analyzed, as shown in Figure 3. From the figure, the causal circuit involving the subject has three main parts.

1) For customers, the greater the number of demand response project inputs, the greater is the number of subsidies. Therefore, the direct revenues of customers who participate in demand response will increase. However, the transfer of load increases that lead to the decline of customers’ satisfaction, which will affect customer participation level and constitute a negative cycle.

2) For electricity retailers, as the dispatcher of demand response, the greater the number of demand response project inputs is, the greater the subsidy that can be earned by the electricity retailers will be. When the load rate increases, the power generation cost of the unit and the electricity purchase cost of retailers both decrease; thus, the efficiency of the electricity retailers increases, constituting a positive cycle.

3) Electricity producers are also among the beneficiaries of the demand response. When the load rate is increased, the cost of the generator decreases and there are increased benefits to electricity producers. However, the loss of electricity generation owing to the load reduction will affect the advantages of electricity producers and constitute a negative cycle.

#### 2.4.3. Development of Simulation Model

According to the analysis of the causal circuit diagram [21], the simulation model can be divided into six modules, i.e., the customer module, subsidy module, electricity retailer module,
electricity price module, electricity producer module, and load module, as shown in Figure 4.

(1) **Customer Module.** For this module, this paper mainly considers customer benefits for two demand response policies, namely, the price-based and incentive-based policies. The relationship between the parameters in the model is as follows.

\[ C_c \cdot R = C_{DR} \cdot R + C_p \cdot R - A_{G-C} \cdot R \]  
\[ \Delta R_{u} \cdot R = \Delta R_{TOU-M} \cdot R/C_{c} \cdot R \times 100\% \]  
\[ \Delta D_c \cdot R = \text{DELAY} \left( \left( D_{goal} - D_c \cdot R \right) \right. \]  
\[ \times \left( \Delta R_{u} \times \alpha + R_{s} \times \beta \right), t_1, 0 \]  
\[ D_c \cdot R = \text{INTEG} (\Delta D_c \cdot R, 0.01) \]  
\[ R_{u} \cdot R = \text{INTEG} (\Delta R_{TOU-M} \cdot R, 0) \]  
\[ S_{ed} \cdot R = C_{E} \cdot R - C_{a} \cdot R \]  
\[ C_{E} \cdot R = Q_{E} \cdot R \times P_{p} \]  
\[ C_{a} \cdot R = Q_{a} \cdot R \times P_{p} + Q_{p} \cdot R \times P_{p} + Q_{g} \cdot R \times P_{g} \]  
\[ R_{TOLU-S} \cdot R = 1 - \Delta Q_{ARS} / Q_{ARS} \]
Figure 4: Simulation model of comprehensive benefit assessment.

where $C_c$ is the cost of customers who participate in DR, $C_{DR}$ is the response cost of the price-based DR, $C_p$ is the equipment cost of price-based DR, $C_g$ represents the government subsidies to customers, $\Delta R_p$ is the added rate of return, $\Delta R_{TOU-M}$ is the added monthly revenue of TOU (time-of-use), $\Delta D$ is the added participation level of price-based DR, and $D_{goal}$ is the target participation level of price-based DR. $D_c$ represents the participation level, $R_0$ is the satisfaction of the electricity-usaging mode, $\alpha$ is the impact factor of the added rate of return, $\beta$ is the impact factor of the satisfaction of the electricity-usaging mode, and $t_1$ is the delay time. $R_0$ is the direct revenue of customers who participate in DR, $S_d$ is the daily electricity tariff savings of TOU customers, $C_d$ is the original daily electricity tariff before DR, $C_{\text{electricity}}$ is the daily electricity tariff after TOU, $Q_E$ is the original daily electricity consumption before DR, $P_0$ is the electricity price during the flat period, and $Q_f$ is the electricity consumption during the peak period. $P_f$ represents the electricity price during the peak period, and $Q_f$ is the electricity consumption during the peak period. $Q_d$ is the electricity consumption during the valley period, $P_d$ is the electricity price during the valley period, and $\Delta R_p$ is the transition rate of the satisfaction electricity-usaging mode.

$R_{TOU-M}$ is the customers' satisfaction of the electricity-using mode who participates in the TOU. $t_2$ is the sensory delay, $\Delta Q_{\text{ABS}}$ is the sum of the absolute value of the transferred electricity who participate in TOU, and $Q_d$ is the original daily electricity consumption in the area.

(2) Load Module. In this module, the design function mainly considers load changes during the peak period, which is given as follows.

$$\xi_b = \frac{(Q_f + Q_p + Q_{\text{G}})}{(24 \ast L_p)}$$ (29)

$$L_{pR} = L_{pR} + R \ast (1 + \delta_t)$$ (30)

$$\xi_f = L_{apR} \ast L_{pR} \ast 100\%$$ (31)

$$L_{aR} = L_{pR} - L_{apR}$$ (32)

$$\xi^a = \frac{(Q_f + Q_p + Q_{\text{G}})}{(24 \ast L_{aR})}$$ (33)

$$\Delta \xi_p = \xi^a - \xi_b$$ (34)
wherein $\xi_b$ is load rate before DR. $L_p$ is load of the region in peak period. $L_p^0$ is the initial value of load in peak period. $\delta_l$ is the natural growth rate of load. $\zeta_l$ is the ratio of avoidable load in peak period. $L_{ap}$ is the avoidable load in peak period. $\xi_b$ is load rate after DR. $Q_f^p$ is regional electricity consumption in peak period after TOU. $Q_f^s$ is regional electricity consumption in flat period after TOU. $Q_d^s$ is regional electricity consumption in valley period after TOU. $\Delta \xi_b$ is increase ratio of load rate.

(3) Electricity Producer Module. Here, the electricity producer module mainly considers two factors, including the efficiency and cost of power generation. Consider the cost reduction of the start-up and shutdown and of the power generation as the junction point in the model, which is shown as follows.

$$B_{ac}, R = B_{ai}, R + B_{ar}, R + B_{au}, R$$

$$\Delta B_{ai} = u_{ai} \times L_{ap} \times \gamma_{c-c}$$

$$\Delta B_{ar} = u_{ar} \times Q_{re} \times \gamma_{c-c}$$

$$\Delta B_{au} = \eta \times \gamma_{c-c} \times Q_d^s \times P_c \times \Delta \xi_b \times \lambda_{c-c}$$

$$U_s = U_{so} \times (1 - \Delta \xi_b \times \lambda_{c-c})$$

$$U_{pc} = U_s \times \theta_s + U_x \times \theta_c + U_{\varepsilon}$$

$$P_{go} = \text{INTEG} (\Delta P_{go}, 0.03)$$

$$\Delta P_{go} = \frac{(P_{oe} - P_{go})}{t_4}$$

$$\Delta L_p = P_{go} \times Q_{re}$$

$$L_p = \text{INTEG} (\Delta L_p, 0)$$

where $P_p$ is the power generation efficiency. $B_{ai}$ is excusable investment cost. $B_{ar}$ is excusable operating cost. $B_{au}$ is excusable cost of start-up and shutdown. $\Delta B_{ai}$ is monthly excusable investment cost of power generation. $u_{ai}$ is unit excusable investment cost of power generation. $\gamma_{c-c}$ is capacity-reduction factor of customer-electricity producer. $\Delta B_{ar}$ is monthly excusable operating cost of power generation. $u_{ar}$ is unit excusable operating cost of power generation. $\gamma_{c-c}$ is electricity reduction factor of customer-electricity producer. $Q_{re}$ is load reduction of TOU. $\Delta B_{au}$ is unit coal consumption of thermal power. $Q_d^s$ is daily regional electricity consumption after DR. $P_c$ is price of electric coal. $\lambda_{c-c}$ is the correlation factor of load rate and coal consumption. $U_s$ is unit cost of start-up and shutdown. $U_{pc}$ is the initial value of cost of start-up and shutdown. $U_{\varepsilon}$ is impact factor of cost of start-up and shutdown. $\theta_s$ is impact factor of capacity cost. $U_{\varepsilon}$ is unit capacity cost. $U_{\varepsilon}$ is other generation costs. $P_{go}$ is the price of on-grid electricity. $\Delta P_{p}$ is the regulation rate of price of on-grid electricity. $P_{oe}$ is expected generation price. $\Delta L_p$ is monthly sale loss of power generation. $L_p$ is the loss of power generation.

(4) Electricity Price Module. For this module, the main consideration is the design function of the electricity price during the peak period, in the flat period, and in the valley period, which are given as follows.

$$\Delta P_p = \frac{(P_{oe} - P_p)}{t_4}$$

$$P_f = P_p \times \phi_f$$

$$P_g = P_p \times \phi_g$$

$$\tilde{p} = \frac{\sum_{i=f,p,g} (Q_i^p \times P_i)}{\sum_{i=f,p,g} Q_i^p}$$

$$P_{be} = u_c + P_{go}$$

$$\Delta u_c = u_{pro} - u_{pe}$$

$$u_{pe} = \tilde{p} - p_{go}$$

where $\Delta P_p$ is the regulation rate of benchmark price. $P_{be}$ is the expected benchmark price. $t_4$ is the adjustment time. $\phi_f$ is the peak-to-flat electricity price ratio. $\phi_g$ is the valley-to-flat electricity price ratio. $\tilde{p}$ is the average electricity price. $u_c$ is expected profit of electricity supply. $\Delta u_c$ is the regulation rate of profit of electricity supply. $u_{pro}$ is initial profit of power supply. $u_{pe}$ is unit profit of power supply.

(5) Electricity Retailer Module. This module mainly considers the relationship between the efficiency and the cost of electricity retailers, which is shown as follows.

$$B_s = B_{ai} + B_{ar} + B_{ic}$$

$$\Delta B_{se-M} = (S_{es} + S_{net}) \times 30$$

$$B_{ai} = A_{G-S} + A_{P-S}$$

$$A_{p-S} = B_p \times \phi$$

$$C_S = C_{DE} + C_{\varepsilon} - A_{G-S} - A_{P-S}$$

$$B_{ic} = L_p + Q_{re} \times P_v$$

where $B_s$ is the income of electricity retailers. $B_{ai}$ represents the revenues from the sale of electricity. $B_{ar}$ is the revenue from incentives. $B_{ic}$ is the cost reduction of electricity purchase of electricity retailers. $\Delta B_{se-M}$ is monthly income owing to electricity sales. $A_{G-S}$ represents the government subsidies to electricity retailers. $A_{P-S}$ represents the subsidies by electricity producers to electricity retailers. $\phi$ is benefit-sharing proportion of electricity producers. $C_S$ is the cost of electricity retailers. $C_{EDR}$ is the management cost of DR. $C_{\varepsilon}$ represents other costs to electricity retailers participating.
in DR, \( p_v \) is average price of electricity transmission and distribution.

(6) \textit{Subsidy Module}. This module mainly considers the subsidy between the government, the electricity retailers, the electricity producers, and the customers, which is given as follows.

\[
A_G = A_{G-C} + A_{G-S}
\]

where \( A_G \) represents the total amount of government subsidies.

3. Results and Discussion

This paper considers an example a region in China that collects generated data of a typical daily load, considers the different types of customers based on the flexibility of price changes, and calculates the load fluctuation of the different customers and changes in revenue of the electricity producers under the demand response. Typical daily load curves for various customers are shown in Figure 5.

Figure 5 shows that daily load curves of industrial and commercial customers correspond to the primary axis (left side), and those of residential and electric vehicle customers correspond to the secondary axis (right side). The study obtains electricity prices of this area in the peak, flat, and valley periods, as shown in Table 1.

From Table 2, the maximum industrial, commercial, and residential loads all declined after the response, and the load rate increased, with the industrial load rate reaching 0.87. However, the maximum load of electric vehicles increased and the load rate declined, which is related to the particularity of electric vehicles. Combined with the load curve of electric vehicles after the response, its maximum load appears in the valley period, which improves the overall load rate. The total electricity reduction in the peak period reaches 5806.6 MWh, and the maximum load decreases by 118 MW. Compared with the expected plan, the maximum load reduction meets the requirements, and the compliance rate of electricity reduction is 96.78%, so it completes the requirements of the electricity producers.

<table>
<thead>
<tr>
<th>User Category</th>
<th>Average electricity price after response ($/MWh)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Peak</td>
</tr>
<tr>
<td>Industry</td>
<td>165.05</td>
</tr>
<tr>
<td>Residents</td>
<td>83.70</td>
</tr>
<tr>
<td>Commerce</td>
<td>181.59</td>
</tr>
<tr>
<td>Electric vehicles</td>
<td>223.70</td>
</tr>
</tbody>
</table>

**Table 1**: Distribution of time-of-use electricity price.
Table 2: Load change data before and after the demand response.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Industry</th>
<th>Commerce</th>
<th>Residents</th>
<th>Electric vehicles</th>
<th>Total load</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum load (MW)</td>
<td>Before the response</td>
<td>17,400</td>
<td>3,744</td>
<td>277</td>
<td>103</td>
</tr>
<tr>
<td></td>
<td>After the response</td>
<td>16,300</td>
<td>3,600</td>
<td>260</td>
<td>130</td>
</tr>
<tr>
<td>Average load (MW)</td>
<td>Before the response</td>
<td>14,226</td>
<td>2,274</td>
<td>196</td>
<td>73</td>
</tr>
<tr>
<td></td>
<td>After the response</td>
<td>14,193</td>
<td>2,254</td>
<td>176</td>
<td>74</td>
</tr>
<tr>
<td>Load rate (MW)</td>
<td>Before the response</td>
<td>0.82</td>
<td>0.61</td>
<td>0.71</td>
<td>0.71</td>
</tr>
<tr>
<td></td>
<td>After the response</td>
<td>0.87</td>
<td>0.63</td>
<td>0.68</td>
<td>0.57</td>
</tr>
<tr>
<td>Consumption during peak period (MWh)</td>
<td>Before the response</td>
<td>127,970</td>
<td>23,184</td>
<td>2964</td>
<td>546</td>
</tr>
<tr>
<td></td>
<td>After the response</td>
<td>123,520</td>
<td>22,000</td>
<td>2484</td>
<td>495</td>
</tr>
<tr>
<td>Decrease in consumption during peak time (MWh)</td>
<td>4,450</td>
<td>1,184</td>
<td>480</td>
<td>51</td>
<td>6,165</td>
</tr>
</tbody>
</table>

From Table 3, the purchase cost of all customers after the response is reduced. In addition, considering the additional subsidies, the customers’ revenues are increased. The response degree and the additional revenue of industrial customers are both the highest.

3.2. Calculation of Dispatch Cost for Electricity Producers. Assume that the power generation above the minimum load line is derived from the thermal power units. In this example, the minimum load before the response is 11,705 MW, and the minimum load after the response is 12,870 MW. Therefore, it stipulates that the power generation, which is higher than 11,705.2 MW, be derived from thermal power units. Nine 600-MW and ten 300-MW thermal power units were used as generating units, and four 400-MW thermal power units were used for peak adjusting. The operating coal consumption rate of the 600-MW thermal power units is 360 g/kWh, that of the 300-MW thermal power units is 370 g/kWh, and that of the 200-MW thermal power units is 378 g/kWh. The coal consumption rate of the start-up and shutdown is 5 g/kWh, and the unit coal price is $57.97/ton. According to the load fluctuation before and after the response, the start-up and shutdown cases of units in different periods are obtained. According to the results, based on the minimum generation load, the maximum increased
Table 3: Cost fluctuations of customers (thousands of dollars).

<table>
<thead>
<tr>
<th></th>
<th>Industry</th>
<th>Commerce</th>
<th>Residents</th>
<th>Electric vehicles</th>
</tr>
</thead>
<tbody>
<tr>
<td>Purchase cost before the response</td>
<td>35,773.36</td>
<td>6,982.01</td>
<td>319.14</td>
<td>301.32</td>
</tr>
<tr>
<td>Purchase cost after the response</td>
<td>35,588.51</td>
<td>6,968.07</td>
<td>283.23</td>
<td>296.12</td>
</tr>
<tr>
<td>Cost reduction</td>
<td>184.86</td>
<td>13.94</td>
<td>35.91</td>
<td>5.20</td>
</tr>
<tr>
<td>Reduction in consumption during peak period</td>
<td>6,449.28</td>
<td>1,715.94</td>
<td>695.07</td>
<td>73.91</td>
</tr>
<tr>
<td>Subsidies</td>
<td>644.93</td>
<td>171.59</td>
<td>69.51</td>
<td>7.39</td>
</tr>
<tr>
<td>Revenue increase value</td>
<td>829.78</td>
<td>185.54</td>
<td>105.42</td>
<td>12.59</td>
</tr>
</tbody>
</table>

Table 4: Comparison of coal consumption cost before and after the response.

<table>
<thead>
<tr>
<th></th>
<th>Before the response</th>
<th>After the response</th>
<th>Descent value</th>
<th>Descent rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operating coal consumption (ton)</td>
<td>44,272.36</td>
<td>33,255.66</td>
<td>11,016.7</td>
<td>0.249</td>
</tr>
<tr>
<td>Operating cost/(thousands of dollars)</td>
<td>2,566.51</td>
<td>1,927.86</td>
<td>638.65</td>
<td>0.249</td>
</tr>
<tr>
<td>Start-stop capacity/MW</td>
<td>6,570.80</td>
<td>4,530.00</td>
<td>2,040.80</td>
<td>0.311</td>
</tr>
<tr>
<td>Start-stop cost/(thousands of dollars)</td>
<td>3.81</td>
<td>2.63</td>
<td>1.18</td>
<td>0.311</td>
</tr>
<tr>
<td>Total cost/(thousands of dollars)</td>
<td>2,570.32</td>
<td>1,930.49</td>
<td>639.83</td>
<td>0.249</td>
</tr>
</tbody>
</table>

Load capacity before the response is 9191.8 MW, and it is only 6873 MW after the response. Therefore, the peak adjusting capacity decreases by 2318.8 MW. During the peak adjusting period before the response, there were 24 start-stop times of units, and, after the response, there were only nine times. Thus, the coal consumption cost before and after the response can be calculated. The coal consumption cost includes only the required thermal power coal consumption cost, which is outside the basic load (minimum load), as shown in Table 4.

From Table 4, the electricity producers can realize savings in the coal consumption cost of $639,830.00 thousand dollars after the response. In addition, owing to the reduction of the reserve capacity for peak adjusting, the input cost of power generation equipment incurred by electricity producers will be reduced, and the equipment-related maintenance cost will be reduced. Therefore, after customers respond to the load reduction, it is beneficial for electricity producers to reduce cost. However, because of the reduction in the total electricity consumption, the interest by electricity producers to generate electricity sales will be reduced. Assume that the price of on-grid electricity is fixed at $43.48/MWh. Combined with the generating capacity before and after the response, the specific electricity sale revenues can be calculated. Among them, the power generation revenue before the response is $6,715,810.00, and it is $6,456,780.00 thousand dollar after the response, so it decreases to $268,030.00 thousand dollar. Compared to these varying incomes and cost, the total revenue of electricity producers is still increased.

Although the government provides subsidies to customers, it would increase the financial burden from the perspective of the environmental emission reduction, and motivating customers to respond to load reduction is beneficial for reducing carbon emissions, thereby reducing the environmental governance cost. Assume that the CO₂ emission of standard coal is 2.46 tCO₂/tee, and the NOx emission of standard coal is 0.0156 NOx t/tee. The reduction in the environmental emission before and after the response is shown in Table 5.

Table 5: Comparison of environmental emission reduction.

<table>
<thead>
<tr>
<th></th>
<th>CO₂ emission (ton)</th>
<th>NOx emission (ton)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Before the response</td>
<td>10.88</td>
<td>0.07</td>
</tr>
<tr>
<td>After the response</td>
<td>8.17</td>
<td>0.05</td>
</tr>
<tr>
<td>Emission reduction</td>
<td>2.71</td>
<td>0.02</td>
</tr>
</tbody>
</table>

From Table 5, by realizing the generation scheduling under a demand response, the cost of government subsidies for environmental carbon-emission reduction is $0.636/kg, and the cost of NOx emission reduction is $4.06/t.

3.3 Comprehensive Benefit Assessment. The results of the example are used as the basic data of the simulation model, and other relevant parameters are set, which is shown in Table 6.

These parameters are inputted into the simulation and operate combined with the functional relationship between other parameters, and the result is shown in Figure 8.

3.3.1 Degree of Customer Participation. From Figure 8, all kinds of customers will cause a large proportion of customers to participate in the initial stage, so it will reduce the load during the peak period and increase the load during the valley period. However, with the natural growth trend of the load, the load rate will subsequently reduce, leading to a decrease in the degree of customer participation, thus requiring more incentives and price intervention to encourage customers to participate. In addition, combined with the delay settings, it causes fluctuations in the degree of customer participation. However, because the customer’s variable load is limited by its own characteristics, after a long time, the degree of customer participation will become constant. In this case, the degree of participation of industrial customers remains fixed at around 30%, around 27% for commercial customer, around 10% for residential customers, and around 42% for electric vehicle customers. The electrical elasticity of electric vehicles
### Table 6: Parameter design.

<table>
<thead>
<tr>
<th>Customer category</th>
<th>Delay time</th>
<th>Commerce</th>
<th>Residential</th>
<th>Electric vehicles</th>
</tr>
</thead>
<tbody>
<tr>
<td>Delay settings</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Sensory delay</td>
<td>1</td>
<td>1</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>Adjustment time of power supply profit</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Adjustment time of benchmark price</td>
<td>6</td>
<td>6</td>
<td>6</td>
<td>6</td>
</tr>
<tr>
<td>Adjustment time of on-grid tariff</td>
<td>6</td>
<td>6</td>
<td>6</td>
<td>6</td>
</tr>
<tr>
<td>Electricity price settings</td>
<td>Peak-to-flat electricity price ratio</td>
<td>1.67</td>
<td>1.67</td>
<td>1.5</td>
</tr>
<tr>
<td></td>
<td>Valley-to-flat electricity price ratio</td>
<td>0.33</td>
<td>0.33</td>
<td>0.5</td>
</tr>
</tbody>
</table>

---

**Figure 8:** Comparison of degree of customer participation.

**Figure 9:** Trends of load rate change and avoidable peak load change.

When the peak load reduces, it will promote the increase of the load rate, thus resulting in the trends of the two becoming similar. However, as the natural load increases, the trend of the degree of customer participation becomes stable, and the adjustable peak load ratio reaches the upper limit, so the avoidable peak load ratio declines. Therefore, the promotion proportion of the load rate is restricted and finally tends to smoothen the fluctuations. Finally, in this case, the avoidable peak load ratio stabilizes at around 6% and at around 4% as the promotion proportion of load rate stabilizes. Overall, it can increase the load rate and increase the peak load ratio through the customer response; therefore, the overall effect is excellent.

**3.3.3. Analysis of Emission Reduction Efficiency.** From Figure 10, the total amount of government subsidies is increasing. However, the degree of customer participation tends to be stable in the latter period, which is ineffective with respect to further increasing investments, and thus the total amount of investment subsidies tends to be flat. To realize a reduction in carbon emissions, the increased carbon-emission reduction first increases and then decreases, which is consistent with the change of load rate. The impact of the load rate fluctuation on the generating capacity of thermal power has a certain delay and appears as the curve of Figure 10. For the unit cost of emission reduction subsidies, the overall trend declines and finally becomes stable, indicating...
that the government can achieve the desired effects and reduce carbon emissions by investing in the demand response project. At the same time, with the increase of the scale, the unit cost of the emission reduction subsidies will also be reduced.

3.3.4. Comprehensive Benefit Analysis. From Figure 11, after the implementation of the demand response, all of the stakeholders have good efficiencies. Among them, the electricity producers obtain the highest efficiency in the process of demand response dispatching. Because of the increased load rate and the decreased peak load ratio, the generation side encounters a reduction in the related costs, such as the reserve capacity cost and the start-stop cost, thus reducing the overall costs. Secondly, with respect to the customers, although the change in electricity habits will lead to a decrease in the customer-electricity-using satisfaction, the peak load subsidies will reduce the electricity cost of customers. In addition, when the load rate increases, the price of the on-grid electricity will reduce, and then the sale price of electricity retailers will decrease by a certain percentage, which further reduces the electricity cost of customers. Finally, for the electricity retailers, there is a need to increase the corresponding equipment costs and management costs in response to the load-reduction plan. However, owing to the decrease in the electricity purchase cost, the overall efficiencies of electricity retailers are still increased. According to the simulation results, the growth in the efficiency of electricity retailers is the slowest.

4. Conclusions

The paper puts forward that the customer group responds to the retailers’ participation in the power generation dispatching model, analyzes the market behavior of the customer group, the electricity seller, and the power producer, studies the comprehensive benefits of various stakeholders, and provides theoretical support for the sales operators to participate in power generation scheduling optimization. The overall efficiencies of customers responding to electricity retailers involved in generation dispatching exhibit good performance, and the increase in efficiency is greater than the cost fluctuation for all of the stakeholders. The electricity producers proposed the load-reduction plan, the electricity retailers implement the dispatching, and government determines the subsidy policy. The electricity retailers stimulate customers to respond by implementing price measures and incentives to change electricity usage habits of customers and obtain benefits from the process. This results in a win-win scenario.

(1) Customers who respond to electricity retailers involved in generation dispatching can make the load curve smooth and increase the load rate. For different types of customers, the degree of participation of electric vehicles is the highest, but industrial and commercial customers have the greatest impact on the total load rate. Therefore, there is a need to increase the demand response measures to industrial and commercial customers, and they should be stimulated to participate in dispatching in order to maximize the increase in the load rate.

(2) From the analysis of the electricity cost fluctuation of various customers, as well as the profit fluctuation of electricity retailers and that of electricity producers, customers who respond to electricity retailers involved in generation dispatching would be able to achieve a win-win situation. In addition, when the environmental costs are considered, a low unit input cost is incurred by government to realize environmental governance.

(3) The comprehensive benefit assessment results show that the participation level of various customers is generally stable, and the degree of participation of electric vehicles is the highest. The load increase ratio can reach around 4%, and the avoidable peak load ratio can reach around 6%. The investment cost of the unit emission reduction of government is also decreased year on year. Moreover, the investment cost required to realize carbon-emission reduction is about $0.636/kg.

Data Availability

The initial data of the dissertation mainly comes from the Project Research. Some data have confidentiality agreements. Except for the data mentioned in the dissertation can be disclosed, other data cannot be disclosed due to confidentiality issues. Some of the data is from the official website at http://www.stats.gov.cn/.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Acknowledgments

The paper is supported by the National Science Foundation of China (Grant no. 71573084) and the Shanghai Municipal Social Science Foundation (no. 2018EGL005).
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