Evaluation of the Implementation Effect of Power Demand Response under the Background of the New Power Reform and Electricity

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Abstract. In recent years, more and more regions have carried out demand response projects. It is urgent to construct an evaluation indicator system and comprehensive evaluation model to evaluate the implementation effect of power demand response under the background of the new power reform and electricity. This paper uses literature research, expert consultation and frequency statistical methods to construct an evaluation indicator system for power demand response implementation in the context of demand response new power reform and electricity; and combine the TOPSIS method with the grey correlation evaluation to construct a grey relational ideal point combination analysis and evaluation model; finally, the theory is applied to practice, to Beijing, Shanghai, Jiangsu and Foshan. The case study of the city is an example to verify the effectiveness of the evaluation model.

1. Introduction

With the rapid development of China’s economy, the demand for power resources is increasing, and the peak-to-valley difference of power grid load is increasing. It is more and more difficult to balance the supply and demand balance of power resources by relying solely on the power supply side. At present, China has implemented a series of demand response (DR) pilot projects in Shanghai, Jiangsu, Beijing, Foshan and other provinces and cities.

Based on the above background, domestic and foreign scholars have done relevant research and discussion in theory. Foreign scholars use the system model method to estimate and simulate the demand response effect in the demand response evaluation. Su, Chua-Liang proposed a quantitative evaluation method for demand response to users in different market environments, and designed a centralized compound bidding market clearing mechanism [1]. According to the analysis of relevant data in Germany, Vardakas JS found that the demand response reform measures only on the sales side could not mobilize the enthusiasm of power users [2]. Adela Conchado comprehensively assesses the benefits of the Spanish family's potential disaster recovery plan. The results show that under current conditions, the power generation system has relatively low returns and needs to address costs and the problem of income distribution [3]. E.A.M. Klaassen describes a method for modeling long-term demand response
gains from a system perspective, and combines the actual data of the Dutch power system to prove the applicability of the method [4].

Domestic scholars' research on demand response evaluation mainly focuses on the evaluation of benefits and effects. In the aspect of benefit evaluation, Wang Dongrong put forward the measuring principle and method of short-term and medium and long-term economic benefits of demand response [5]; Zeng Bo proposed by introducing interval data indicators. An interval gray correlation ideal point analysis method combining expert scoring and interval center point distance method [6]; Shen Yunyi established the cost-effectiveness of demand response based on the analysis of the cost and benefit of each participant in the demand response project. The model is empirically analyzed by a numerical example [7]. In terms of effect evaluation, Wang Zhijie established the evaluation indicator system and model of demand response resources, and combined with the data of a certain region of California [8]. Based on the user response characteristics of the price elasticity matrix, Sun Wei constructed the demand response planning evaluation indicators for the performance and economic indicators [9]. Xie Chang divides users into different credit grades to allocate capacity, and proposes a comprehensive response evaluation coefficient for single response, which evaluates the response effect of a specific user and divides the credit rating [10]. Qi Xianjun used the sequential Monte Carlo simulation method to evaluate the operational reliability of the distribution network, and obtained the reliability indicator at each load level [11].

It can be seen that the issues related to DR implementation evaluation in the context of new power reform and electricity have received wide attention from scholars. However, the existing results still have the following shortcomings: (1) in the context of new power reform and electricity, the implementation effect of demand response is more focused on the efficiency of demand response implementation and user initiative. The selection of current indicators cannot clearly reflect its characteristics; (2) at present, domestic demand response evaluation indicators are based on a single perspective and cannot fully meet the new power reform and electricity background. The objective needs of the evaluation of DR implementation effects; (3) In terms of evaluation methods, at present the effect of demand response implementation is more systematic methods such as system dynamics and load simulation, and there are fewer comprehensive evaluation methods.

2. Evaluation system for the implementation of power demand response under the background of the new power reform and electricity

2.1. Design indicator criteria layer

This paper conducts frequency statistics on the influencing factors of the demand response implementation in 69 papers. As shown in Figure 1, it can be found that scholars mainly analyze the influencing factors from two aspects, on the one hand, from user response consciousness and load, reduction, and interactivity directly measure the influencing factors of demand response, and on the other hand, social, economic, and environmental factors that directly measure the effect of demand response.

![Figure 1. Factors affecting the implementation of demand response](image)
On the basis of the frequency analysis of the literature, 10 experts from who have been engaged in the power industry for more than 10 years have been fully consulted, and the above factors have been summarized: "Power generation, power grid, and user-side economic level" has been merged into "economic effects". "User response awareness" and "interactivity", "load response quality" merged into "demand response execution effect"; "environment", "energy utilization" merged into "environmental effect"; "social management", "safety" "Reliability" is merged into "social effects." Finally, five aspects are designed to evaluate the performance evaluation system of power demand response under the background of the new power reform and electricity: demand response execution effect, load reduction effect, economic effect, environmental effect, and social effect.

2.2. Evaluation Indicators Primary Selection

This paper uses the literature research method to sort out a statistical analysis of the literature on demand side management, demand response, and demand response evaluation published in recent years in mainland China journals. In recent years, there have been 34 published articles in mainland China journals and magazines including in 10 foreign articles, 13 excellent master's thesis, 8 doctoral thesis, 4 series of guidance books, a total of 69 articles, 22 indicators were selected and integrated into the corresponding criteria layer. As shown in Table 1.

| Target layer | Criteria layer | Indicator layer | nature | unit |
|--------------|----------------|-----------------|--------|------|
| Demand response execution effect \(X_1\) | User average response frequency \(X_{11}\) | positive | Times /a |
| | Average user response time \(X_{12}\) | positive | h/a |
| | Average response duration \(X_{13}\) | inverse | h/ Times |
| | Average response time \(X_{14}\) | inverse | min |
| | User participation rate \(X_{15}\) | positive | % |
| | Load completion rate \(X_{16}\) | positive | % |
| Load reduction effect \(X_2\) | Load rate increase \(X_{21}\) | positive | % |
| | Peak-to-valley difference reduction \(X_{22}\) | positive | GW |
| | Peak load reduction \(X_{23}\) | positive | GW |
| | Electricity reduction \(X_{24}\) | positive | GW·h |
| Economic effect \(X_3\) | User side economic effect \(X_{31}\) | positive | ¥ Ten thousand |
| | Grid side economic effects \(X_{32}\) | positive | ¥ Ten thousand |
| | Power generation side economic effect \(X_{33}\) | positive | ¥ Ten thousand |
| Environmental effect \(X_4\) | Pollution gas emission reduction effect \(X_{41}\) | positive | / |
| | Renewable energy utilization growth rate \(X_{42}\) | positive | % |
| | Free land consumption \(X_{43}\) | positive | Km\(^3\) |
| Social effect \(X_5\) | Voltage pass rate increase \(X_{51}\) | positive | % |
| | Power supply reliability improvement \(X_{52}\) | positive | % |
| | Power failure frequency reduction rate \(X_{53}\) | positive | % |
| | Average rate of decline per power outage \(X_{54}\) | positive | % |
| | Industrial efficiency \(X_{55}\) | positive | / |
| | Increased user satisfaction \(X_{56}\) | positive | / |
2.3. Indicator Connotation and Measurement

(1) Demand response execution effect

① User average response frequency
It indicates the average number of times each user in the year participates in the demand response reduction load. The higher the frequency of participation in demand response, the higher the enthusiasm of user participation.

$$\text{User average response frequency} = \frac{\text{The sum of each user's participation in the number of demand responses}}{\text{User number}} \quad (1)$$

② Average user response time
It represents the average time that the user participates in the demand response to reduce the load each year. Within the allowable range, the user's annual response time is as long as possible.

$$\text{Average user response time} = \frac{\text{The sum of each user's participation time}}{\text{User number}} \quad (2)$$

③ Average duration of each response
Indicates the duration of each response from the start of the response to the end of the response.

$$\text{Average response duration} = \frac{\text{Total demand response time}}{\text{Total demand response}} \quad (3)$$

④ Average response time
Represents the response time from the receipt of the demand response command to the start of execution. The shorter the response time, the higher the efficiency of the demand response execution.

$$\text{Average response time} = \frac{\text{The sum of user response time}}{\text{Number of users participating in the response}} \quad (4)$$

⑤ Average user participation rate
Indicates the proportion of users who actually participate in the response to the number of invited users. The average user participation rate represents the average of the user participation rate in a year.

$$\text{user participation rate} = \frac{\text{Number of invitees participating in the demand response}}{\text{Total number of invited users}} \quad (5)$$

$$\text{Average user participation rate} = \frac{\text{The sum of user participation rates}}{\text{Total demand response}} \quad (6)$$

⑥ Average load completion rate
The load completion rate represents the ratio of the actual response amount of each demand response item to the regulation target, and the average load completion rate represents the average value of the demand response item load completion rate in a year.

$$\text{Load completion rate} = \frac{\text{Actual response}}{\text{Response event schedule}} \quad (7)$$

$$\text{Average load completion rate} = \frac{\text{Sum of load completion rates}}{\text{Total demand response}} \quad (8)$$

(2) Load reduction effect

① Load rate increase
The higher the load rate, the more stable the system is.

$$\text{Load factor} = \frac{\text{Average system load}}{\text{Maximum system load}} \quad (9)$$
Load rate increase = Load rate this year – Last year’s load rate \hspace{1cm} (10)

② Peak-valley difference reduction rate
The difference between the peak and the valley indicates the effect of peak clipping and valley filling. The peak-valley difference reduction rate indicates a decrease in the peak-valley difference due to the implementation of the demand response.

\[
\text{Peak and valley difference} = \text{Maximum system load} - \text{Minimum system load} \hspace{1cm} (11)
\]

\[
\text{Peak—valley difference reduction rate} = \frac{\text{Peak—valley difference without response} - \text{Peak—valley difference after implementing response}}{\text{Peak—valley difference without response}} \hspace{1cm} (12)
\]

③ Peak load reduction
The peak load reduction value due to the implementation of the demand response, reflects the peak clipping capability of the demand response project.

\[
\text{Peak load reduction} = \text{Peak load of demand response system not implemented} - \text{Peak load after implementing a demand response system} \hspace{1cm} (13)
\]

④ Electricity reduction
The amount of electricity reduction scale represents the reduction in electricity consumption due to the implementation of demand response, reflecting the impact of demand response on total electricity consumption.

\[
\text{Electricity reduction} = \text{The amount of electricity that is not implemented in the demand response system} - \text{The amount of electricity after implementing the demand response system} \hspace{1cm} (14)
\]

⑤ Economic effects
The economic effect is generally measured by the difference method, the ratio method, and the difference expression method. This paper chooses the difference method.

1. User side economic effect
The user side economic effect is represented by the user side revenue minus the user side cost. User-side benefits include reduction of revenue from electricity bills, incentive compensation, cost including loss of output value, etc.

\[
\text{User side economic effect} = \text{Reduced electricity bill} + \text{Incentive compensation} - \text{Loss of output value} \hspace{1cm} (15)
\]

2. Grid side economic effects
The economic effect of the power grid side is represented by revenue minus cost. Grid-side benefits include the cost of including optional maintenance costs, including cost of power loss, incentive costs, and so on.

\[
\text{Grid side economic effects} = \text{Free operation cost} - \text{Cost of electricity loss} - \text{Incentive cost} \hspace{1cm} (16)
\]

3. Power generation side economic effect
The economic effect of the power generation side is represented by the revenue minus cost. The revenue from the power generation side includes the cost of the built-in power supply, the operating cost, and the cost of power generation.
(4) Environmental effects

① Pollution gas emission reduction effect
The emission reduction of pollutants indicates the amount of electricity generated by the reduction of demand response.

\[ \text{Pollution gas emission reduction effect} = CO2 \text{ reduction} \times CO2 \text{ emission reduction value} + SO2 \text{ reduction} \times SO2 \text{ emission reduction value} + NOx \text{ reduction} \times NOx \text{ emission reduction value} \] (18)

② Renewable energy utilization growth rate
Indicates the rate of change of renewable energy generation as a percentage of demand response.

\[ \text{Renewable energy utilization growth rate} = \frac{\text{Revenue generation of renewable energy after implementing demand response}}{\text{Revenue generation of renewable energy after demand response is not implemented}} \] (19)

③ Free of land resource consumption
The land-use-free consumption represents the land resource consumption saved by avoiding grid and power supply construction due to the implementation of demand response.

(5) Social effects

① Voltage pass rate increase
The increase in the voltage pass rate refers to the change in the ratio of the time during which the node voltage of the demand response system is within the acceptable range to the total statistical time.

② Power supply reliability improvement
The ratio of the time between the system's power supply reliability and the total statistical time after the implementation of the demand response.

③ Power failure frequency reduction rate
Refers to the rate of decline in the number of system outages after DR implementation.

\[ \text{Power failure frequency reduction rate} = \frac{\text{Reduced power frequency due to implementation demand response}}{\text{Power outage frequency before implementing demand response}} \] (20)

④ System average power outage time reduction rate
Refers to the decrease in the ratio of the total power outage time to the number of power outages after the implementation of the demand response.

\[ \text{System average power outage time} = \frac{\text{The sum of system power outages}}{\text{Number of power outages}} \] (21)

\[ \text{System average power outage time reduction rate} = \frac{\text{Average power outage reduction due to implementation demand response}}{\text{Power outage time before implementing demand response}} \] (22)

⑤ Industrial efficiency
The industrial benefit indicator is a qualitative indicator, which is determined by experts scores, mainly based on the financing of related industries and the support of the results of related projects.

⑥ Increased user satisfaction
The user satisfaction improvement indicator is a qualitative indicator, which is determined by experts' scores, mainly based on the number of relevant complaints received.

3. Establishment of evaluation model for power demand response implementation in the context of new power reform and electricity

3.1. Data standardization processing

In this paper, the vector normalization method is used to standardize the original data, and \( x_{ij} (i=1,2,...,m, j=1,2,...,n) \) is the original data of the \( n \)th evaluation indicator on the \( m \)th scheme.

When the indicator attribute of \( x_{ij} \) is positive,

\[
x'_{ij} = \frac{x_{ij}}{\sqrt{\sum x_{ij}^2}}, x_{ij} > 0
\]

When the indicator attribute of \( x_{ij} \) is inverse,

\[
x'_{ij} = \frac{1}{\sqrt{\sum x_{ij}^2 (1/x_{ij})}}, x_{ij} > 0
\]

When \( x_{ij}=0 \),

\[
y_{ij} = 0
\]

The obtained \( x'_{ij} (i=1,2,...,m, j=1,2,...,n) \) represents the normalized data of the original data of the \( n \)th evaluation indicator on the \( m \)th scheme, \( 0 \leq y_{ij} \leq 1 \).

3.2. Determine indicator weights

3.2.1. Analytic hierarchy method to determine weights

(1) According to the evaluation indicator system, a hierarchical structure is established
(2) Establish a judgment matrix
(3) Consistency test and relative importance calculation

A consistency check is usually performed after the scale, and the calculation formula is

\[
CI = \frac{\hat{\lambda}_{nax} - n}{n - 1}
\]

Because the order of the judgment matrix is different, CI cannot be uniformly measured. The average random consistency indicator is introduced, and the calculation formula is

\[
CR = \frac{CI}{RI}
\]

CR is the average random consistency ratio, RI is the average random consistency indicator.

When \( C.R \leq 0.10 \), the matrix passed the consistency test, and the average random consistency indicator test values are shown in Table 2.

| Order | 3   | 4   | 5   | 6   | 7   | 8   | 9   | 10  | 11  | 12  | 13  | 14  | 15  |
|-------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| RI    | 0.52| 0.89| 1.12| 1.26| 1.36| 1.41| 1.46| 1.49| 1.52| 1.54| 1.56| 1.58| 1.59|

(4) Determine the weight subjective

1) Find the eigenvector of the judgment matrix \( W=(w_1, w_2, \cdots, w_n) \)
2) Normalize the matrix W by column

\[ w_{ij} = \frac{w_{ij}}{\sum_{i} w_{ij}}, \quad i = 1, \ldots, m; j = 1, \ldots, n \]  

(28)

3) Add the sum by the row \( \bar{W}_i \)

\[ \bar{W}_i = \sum_{j} w_{ij} \]  

(29)

4) Normalized weight coefficient \( W_i \)

\[ W_i = \frac{\bar{W}_i}{\sum_{i} \bar{W}_j} \]  

(30)

5) Calculation of the comprehensive importance

Assume that the overall importance of all elements \( A_1, A_2, \ldots, A_m \) in the upper level is \( a_1, a_2, \ldots, a_m \), and the relative importance of the elements \( W_1, W_2, \ldots, W_n \) corresponding to \( A_i \) is \( \left( b'_1, b'_2, \ldots, b'_n \right)^T \). If \( W_j \) has no connection with \( A_i \), then there is \( b'_j = 0 \). The comprehensive importance of the element \( W_j \) is

\[ b_j = \sum_{j=1}^{n} a_i b'_j \]  

(31)

3.2.2. Entropy weight method to determine the weight. Let the standardized data matrix of the evaluation be \( V_{ij} \), there are \( m \) evaluation schemes, \( n \) evaluation indicators, and the steps of calculating the weights by the entropy weight method are described below:

1) Calculate the characteristic weight of the jth indicator

\[ p_{ij} = \frac{V_{ij}}{\sum_{i} V_{ij}} \]  

(32)

2) Calculate the entropy of the jth indicator

\[ H_j = -\frac{1}{\ln m} \sum_{i=1}^{m} p_{ij} \ln p_{ij} \]  

(33)

When \( p_{ij} = 0 \) or \( p_{ij} = 1 \), \( \ln 0 = 0 \)

3) Calculate the difference coefficient of the jth indicator

\[ G_j = 1 - H_j \]  

(34)

\( G_j \) reflects the importance of the jth indicator to the overall goal. For a certain indicator \( X_j \), the smaller \( X_j \) is, the larger \( H \) is, the smaller \( G_j \) is. If each scheme \( X_j \) is equal, then \( G_j = G_{\text{min}} = 0 \), at which point the indicator \( X_j \) has no meaning for the comprehensive evaluation.

4) Calculate the entropy weight

\[ w_{ij} = \frac{G_j}{\sum_{j} G_j} \]  

(35)

3.2.3. Combination Empowerment. The geometric mean weighting method determines the combination weight.

\[ W_i = \frac{\theta_i^a \cdot \gamma_i^b}{\sum_{j} \theta_j^a \cdot \gamma_j^b} \]  

(36)
3.3. Gray Correlation Ideal Point Combination Analysis Model

The traditional TOPSIS method cannot accurately reflect the relationship structure between the original sample data in some cases, and it is difficult to ensure the validity of the final evaluation result. Aiming at this problem, this paper combines the Gray relation analysis (GRA) with TOPSIS, and proposes a gray correlation ideal point combination analysis method (GRA-TOPSIS), which overcomes the inherent drawbacks of the original method.

There are m plans for the evaluation system, n indicators, and the matrix after standardization is \( Y \). The specific evaluation steps of the TOPSIS method are as follows.

1. A weighted normalization matrix is calculated based on the normalized data and the combined weight of each evaluation indicator.
   
   \[
   U = \left( u_{ij} \right)_{m \times n} = \left( w_j y_{ij} \right)_{m \times n} = \begin{bmatrix}
   u_{11} & u_{12} & \cdots & u_{1n} \\
   u_{21} & u_{22} & \cdots & u_{2n} \\
   \vdots & \vdots & \ddots & \vdots \\
   u_{m1} & u_{m2} & \cdots & u_{mn}
   \end{bmatrix}
   \]  

2. Determine the ideal solution and the negative ideal solution. The standardized processing indicators have been converted into positive indicators, so the calculation method is as follows.
   
   \[
   U^+ = (u_1^+, u_2^+, \ldots, u_m^+) \quad \text{and} \quad U^- = (u_1^-, u_2^-, \ldots, u_m^-)
   \]  

3. Calculate the Euclidean distance between each practical solution and the ideal solution and the negative ideal solution.
   
   \[
   D_+^i = \sqrt{\sum_{j=1}^{n} \left[ u_{ij} - u_{ij}^+ \right]^2} \quad 
   D_-^i = \sqrt{\sum_{j=1}^{n} \left[ u_{ij} - u_{ij}^- \right]^2}, \quad (i = 1, 2, \ldots, m)
   \]  

4. According to the two Euclidean distances, calculate the relative closeness between each actual scheme and the ideal scheme.
   
   \[
   D^*_i = \frac{D_-^i}{D_+^i + D_-^i}, \quad (i = 1, 2, \ldots, m)
   \]  

5. Calculate the gray correlation coefficient \( \delta_+^i \) and \( \delta_-^i \) based on the normalized matrix \( Y \)
   
   \[
   \delta_+^i = \frac{m \min_{j=1}^{m} \left| y_{ij} - y_j^+ \right| + \theta \max_{j=1}^{m} \max_{j=1}^{m} \left| y_{ij} - y_j^+ \right|}{\max_{j=1}^{m} \max_{j=1}^{m} \left| y_{ij} - y_j^+ \right|}
   \]  

   \[
   \delta_-^i = \frac{m \min_{j=1}^{m} \left| y_{ij} - y_j^- \right| + \theta \max_{j=1}^{m} \max_{j=1}^{m} \left| y_{ij} - y_j^- \right|}{\max_{j=1}^{m} \max_{j=1}^{m} \left| y_{ij} - y_j^- \right|}
   \]  

6. Calculate the gray correlation degree of each scheme:
   
   \[
   r_+^i = \sum_{j=1}^{n} w_j \delta_+^ij \quad \text{and} \quad r_-^i = \sum_{j=1}^{n} w_j \delta_-^ij
   \]  

7. In the TOPSIS method, the larger the \( D_-^i \) is, the closer the scheme is to the positive ideal scheme; in the gray evaluation method, the larger the \( r_+^i \) is, the closer the actual scheme is to the positive ideal scheme. Therefore, in the grey correlation ideal point combination analysis method, the larger \( D_+^i \) and \( r_+^i \) indicates that the actual scheme is closer to the positive ideal scheme, and the larger \( D_-^i \) and \( r_-^i \)
indicates that the actual scheme is closer to the negative ideal scheme. The calculation steps are as follows:

Firstly, the Euclidean distance $D_i^\pm$ and the grey correlation degree $r_i^\pm$ are normalized, and then the combined results are calculated.

$$C_i^+ = p \cdot D_i^+ + q \cdot r_i^+,$$
$$C_i^- = p \cdot D_i^- + q \cdot r_i^-$$  \hspace{5cm} (44)

Where $p$, $q$ are preference coefficients, satisfying $p+q=1$, generally taking $p=q=0.5$;

(8) The larger $C_i^+$ indicates that the actual scheme is closer to the optimal scheme; the larger the $C_i^-$ indicates that the actual scheme is closer to the worst scheme, and the comprehensive closeness of the scheme is calculated accordingly.

$$F_i = \frac{C_i^-}{C_i^- + C_i^+}$$  \hspace{5cm} (45)

(9) Sort each scheme according to the obtained $F_i$. The larger the $F_i$ is, the closer it is to the ideal scheme, and the smaller the $F_i$ is, the further away from the ideal scheme.

4. Example application

This paper selects four cities Beijing, Shanghai, Jiangsu and Foshan for analysis. The data sources of this study mainly include the statistical data of the internal website of the power company and the official website of the National Bureau of Statistics. Due to the lag of the publication of the indicator data, this paper conducts evaluation research based on the 2017 data collected. Power companies have confidentiality requirements for data, so only standardized data after processing is shown in the paper. The original data is normalized according to formulas (23-25), and the processed data is shown in Table 3.

**Table 3. Raw data standardization processing**

| indicator | Beijing | Shanghai | Jiangsu | Foshan |
|-----------|---------|----------|---------|--------|
| User average response frequency X11 | 0.295644 | 0.677517 | 0.517376 | 0.431147 |
| Average user response time X12 | 0.437052 | 0.626047 | 0.413427 | 0.496113 |
| Average response duration X13 | 0.379595 | 0.189797 | 0.795919 | 0.493473 |
| Average response time X14 | 0.355101 | 0.538031 | 0.715581 | 0.498415 |
| User participation rate X15 | 0.465261 | 0.524938 | 0.509466 | 0.498415 |
| Load completion rate X16 | 0.531409 | 0.543389 | 0.486275 | 0.431126 |
| Load rate increase X21 | 0.452154 | 0.575081 | 0.606117 | 0.312187 |
| Peak-to-valley difference reduction X22 | 0.410855 | 0.560653 | 0.671547 | 0.256693 |
| Peak load reduction X23 | 0.305502 | 0.378945 | 0.837091 | 0.249696 |
| Electricity reduction X24 | 0.25024 | 0.596239 | 0.731748 | 0.215459 |
| User side economic effect X31 | 0.397721 | 0.534276 | 0.688164 | 0.287746 |
| Grid side economic effects X32 | 0.245021 | 0.716217 | 0.546586 | 0.358108 |
| Power generation side economic effect X33 | 0.319951 | 0.698076 | 0.538757 | 0.391166 |
| Pollution gas emission reduction effect X41 | 0.453609 | 0.592426 | 0.538757 | 0.391166 |
| Renewable energy utilization growth rate X42 | 0.355939 | 0.648317 | 0.529671 | 0.415262 |
| Free land consumption X43 | 0.481387 | 0.604581 | 0.529785 | 0.349394 |
| Voltage pass rate increase X51 | 0.637406 | 0.453096 | 0.238067 | 0.57597 |
| Power supply reliability improvement X52 | 0.484139 | 0.515373 | 0.3592 | 0.690978 |
| Power failure frequency reduction rate X53 | 0.433693 | 0.648411 | 0.541964 | 0.312648 |
| Average rate of decline per power outage X54 | 0.414156 | 0.649994 | 0.541226 | 0.33624 |
| Industrial efficiency X55 | 0.44586 | 0.543034 | 0.514454 | 0.491589 |
| Increased user satisfaction X56 | 0.437016 | 0.544773 | 0.520827 | 0.490895 |
The subjective and objective comprehensive weights are calculated according to the formula (36). The calculation results are shown in Table 4.

Table 4. Subjective and objective comprehensive weights of each indicator

| Indicator                              | Subjective weight | Objective weight | Combination weight |
|----------------------------------------|------------------|------------------|--------------------|
| User average response frequency X11    | 0.0183           | 0.045042         | 0.033799           |
| Average user response time X12         | 0.0333           | 0.014418         | 0.025796           |
| Average response duration X13          | 0.0278           | 0.112487         | 0.065834           |
| Average response time X14              | 0.0693           | 0.071743         | 0.08301            |
| User participation rate X15            | 0.0481           | 0.001036         | 0.00831            |
| Load completion rate X16               | 0.0728           | 0.004261         | 0.020734           |
| Load rate increase X21                 | 0.1215           | 0.031999         | 0.073406           |
| Peak-to-valley difference reduction X22| 0.0608           | 0.060792         | 0.071573           |
| Peak load reduction X23                | 0.1131           | 0.131177         | 0.143395           |
| Electricity reduction X24              | 0.0327           | 0.133542         | 0.077796           |
| User side economic effect X31          | 0.0471           | 0.053263         | 0.058965           |
| Grid side economic effects X32         | 0.0077           | 0.080839         | 0.029372           |
| Power generation side economic effect X33| 0.0191           | 0.044327         | 0.034255           |
| Pollution gas emission reduction effect X41| 0.1168         | 0.013193         | 0.046214           |
| Renewable energy utilization growth rate X42| 0.0354         | 0.027955         | 0.037035           |
| Free land consumption X43              | 0.0643           | 0.019856         | 0.042065           |
| Voltage pass rate increase X51         | 0.0175           | 0.0606           | 0.038338           |
| Power supply reliability improvement X52| 0.0159           | 0.018095         | 0.019969           |
| Power failure frequency reduction rate X53| 0.034            | 0.03638          | 0.041404           |
| Average rate of decline per power outage X54| 0.0329          | 0.032726         | 0.03863            |
| Industrial efficiency X55              | 0.006            | 0.002738         | 0.004772           |
| Increased user satisfaction X56         | 0.0058           | 0.003532         | 0.005328           |

According to formulas (39-43), the Euclidean distance and the gray correlation degree calculated by the TOPSIS method are normalized, and $p=q=0.5$ is used to calculate the relative proximity $C$ according to the formulas (44). The calculation results are shown in Table 5.

Table 5. The closeness of the implementation effect of the demand response and the ideal plan

| Pilot city    | $D^+_t$ | $D^-_t$ | $r^+_t$ | $r^-_t$ | $C^+_t$ | $C^-_t$ | $C_t$ |
|---------------|---------|---------|---------|---------|---------|---------|-------|
| Beijing       | 0.5857  | 0.2111  | 0.3914  | 0.5513  | 0.3012  | 0.5685  | 0.3464 |
| Shanghai      | 0.4540  | 0.4578  | 0.5510  | 0.4051  | 0.5044  | 0.4295  | 0.5401 |
| Jiangsu       | 0.1239  | 0.8443  | 0.6410  | 0.3665  | 0.7426  | 0.2452  | 0.7518 |
| Foshan        | 0.6599  | 0.1818  | 0.3637  | 0.6306  | 0.2728  | 0.6453  | 0.2971 |

According to the calculation result of relative closeness, the order of the implementation effect of demand response under the background of new power reform and electricity can be obtained: Jiangsu>Shanghai>Beijing>Foshan.

In terms of "demand response execution effect", the performances of the four places are not much different, and Jiangsu is slightly better. At present, the responding users have all passed the screening of the power company to confirm that they have certain responsiveness, and the subsidies are high. The enthusiasm of users to participate is strong. How to make all kinds of users participate and maintain the high enthusiasm of users is a key issue. In terms of response efficiency, the main response is still for
large industrial users, and the amount of invitations is basically completed, but the duration and response
time should continue to improve.

In terms of “load reduction effect”, the four regions have great differences. Jiangsu has been
innovating in the demand response pilot projects every year. There are many types of demand response
projects. In the eleventh period of this year, the domestic demand side bidding model was initiated and
the power will be the user has been subdivided into large industrial users, non-work air conditioner users,
load integrators, etc., and the technology and management methods are at a high level; the Shanghai
demand response project is more for residents and intelligent buildings, and the load reduction effect is
second to Jiangsu; Beijing and Foshan were built with weaker management capabilities and weaker load
reduction effects.

In terms of “economic effects”, Jiangsu and Shanghai have a larger scale of implementation, and the
economic effect is better than that of Beijing and Foshan. Jiangsu has a larger investment in technology
and management, and its economic effect is slightly worse than that of Shanghai. With the end of the
pilot, how to ensure stable financial support is a problem faced by power grid companies.

In terms of “environmental effects” and “social effects”, there is a greater relationship with the
reduction of load. The environmental effects and social effects of the load reduction effect will be
improved, if the effect of the load reduction is good. It is related to the government guidance and
supervision. The government should assume the responsibility to guarantee a stable development of
demand response.

Through analysis and discussion, the experts agreed that the evaluation results are in line with the
actual situation, and the scientific nature of the evaluation system constructed in this paper is confirmed
from the practical level. This result has certain significance for improving the implementation effect of
demand response and improving the management ability of grid companies in demand response. At the
same time, the research results can be applied to the practice of demand response project implementation
and effect evaluation in other regions.

5. Conclusion
According to the results of the implementation effect evaluation of the demand response in the four
cities of Beijing, Shanghai, Jiangsu and Foshan, this paper will propose some management inspirations
from the following four aspects: (1) In terms of the “demand response execution effect”: Increase
publicity, expand participation, and increase user participation. (2) In terms of the “load reduction
effect”: the demand response project should be continuously improved and innovated. (3) In terms of
“economic effects”: establish and improving long-term working mechanism for demand response and
exploring new business models. (4) In terms of “social effects and environmental effects”: speeding up
the process of power marketization and strengthening government responsibility of guidance and
supervision.

Acknowledgements
(1) This paper is funded by the Shanxi Provincial Department of Education's Soft Science Research
Program-Research on Active Response and Incentive Mechanism of Stochastic Power Multi-load
Resources in Shanxi Province Based on Supply Side Reform. (Project No: 2018KRM031)
(2) This paper is funded by the State Grid Tianjin Electric Power Company project - Research and
application of multi-load active response and predictive control technology for random power supply.
(Project No.SGTJDK00DWJS1700034)

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