Demand Response Analysis and Interaction Potential Evaluation of Industry Costumers’ Intelligent Electricity Demand

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Abstract. With the construction of smart grid, power consumption has become more intelligent and interactive. To fully understand the users’ behavior and interaction potential and enhance the competitiveness is problem the power grid companies should focus on. This paper takes industrial users as the research object and divided the costumers through multidimensional analys is. Then establish the index evaluation system and optimization model of interactive potential evaluation from three aspects including economy, technology and practicability. The calculation of interaction potential of different industrial users can provide technical and data support for power grid companies and achieve better “human-grid” interaction.

1. Introduction
As the visual display platform of smart grid construction, smart power consumption is the prerequisite of all the function of smart grid. Guiding economical electricity consumption, managing power consumption habits and constructing a new relationship between grid and users in real time have become the development trend of intelligent power technology. Nowadays, consumers have put forward higher requirements on service concept, mode, contents and quality of the grid companies. In addition to low cost, sage and reliable power supply, the consumer wants more convenient, more diversified, more personalized and more interactive services [1-2].

As the core of interactive service system, smart power consumption is the hub that connects power suppliers and users. The implement of smart power consumption is directly related to the utilization rate and economic operation of grid, and orderly power consumption. It can also have a profound impact on grid construction, energy saving and power quality management. [3] The prominent characteristic of intelligent electricity response is creating open information system and shared information models. It can integrate and dispatch the demand-side resources flexibly, especially emphasis on interaction between users’ information and power [4-5].

The development of smart grid provides technical basis and conditions for users’ participation in the information interaction. It introduced electricity prices as a means to guide users to optimize the consumption behavior based on the traditional unit combination model. Besides, on the generation side, it considered the impact of interruptible load backup on power generation costs and dispatch, this
optimize the coordination of generation and demand side resources. [6] At the same time, as the nation’s largest electricity consumption industry, industrial consumption plays a decisive role in the power consumption of the whole society. Under the environment of smart power consumption, the research on the interactive demand response technology of the industrial area along with analysis on the electrical characteristics and interactive response play important roles in improving the overall performance and operation efficiency of power system. [7-9] At this stage, research on interactive potential evaluation of smart power consumption can help the grid companies better understand the needs of users and enhance the competitiveness under the environment of electricity market reform.

2. analysis on demand response of industrial users

2.1. Industrial user classification

Industrial users are the largest consumers of electricity. They are able to respond quickly to price fluctuations or other motivational signals when participating in smart power consumptions and reduces significant power needs. For industrial users, an important factor affecting the responsiveness of smart power consumption is the ability to regulate the production process. Therefore, according to the characteristics of the production process, this paper divided industrial users into two categories: continuous production industrial users and non-continuous production industrial users:

1. Continuous production industry: the raw materials go through the entire production process in a continuous state. The industrial production mainly finished through chemical or physical changes in the process. The characteristic is the production process has relatively stringent restrictions. The whole process must be completed in order. Continuous production industries include ferrous metal smelting and rolling, steel, cement, non-ferrous metal smelting and pressing, textile, petrochemical and so on.

2. Non-continuous production industry: the raw materials are in a discrete state. The production processes are mainly finished through physical processing and assembly. The characteristic is that there are many components and parts of the production, so the processes are independent and they can be parallel or asynchronous. Non-continuous production industries include general or special equipment manufacturing, electronic equipment manufacturing, food and beverage, transportation equipment manufacturing and handicrafts manufacturing.

Usually, the industrial users have a large amount of electricity loads with high requirement on reliability and safety during the production process. Most industrial production has process and order requirements. Therefore, while making smart demand response plans, the requirements should be considered fully and systematically. Large industrial users can participate in smart power response by reducing production, stop production, rotate days off and planned maintenance.

2.2. Smart power response of industrial users

Under the environment of smart response, according to the hierarchical relationship in the production plans, the industrial users can response to the price signal by shifting the load or response to the excitation signal by reducing the load.

1. Response to excitation signal

The grid companies send the excitation signal and the industrial users will reduce the load after defining the production plan. The smart response plan will be made according to the amount of load reduction. The response mode to excitation signal is shown in Figure 1.
2. Response to price signal

While implementing time-of-use price or real-time price, the industrial users will distribute the production tasks in the most economical way after determining the classification and priority of production plans and defining process constraints. Considering the deviation between actual plans and preassigned plans, the users can reschedule the tasks based on actual situation.

3. Interactive potential evaluation model of industrial users

3.1. Interactive potential evaluation index system of industrial users

According to the principle of establishing an index system, this paper will evaluate the interactive potential from three aspects including economy, technology and practicability. The overall index system is divided into two layers. The first layer includes economic, technical and social indicators. The second layer is the sub-index of the fist, as shown in Figure 2.

![Interactive potential evaluation index system](image)

**Figure 2.** Interactive potential evaluation index system
3.2. Interactive potential evaluation model of industrial users

The interactive potential of industrial users' intelligent electricity is evaluated by the method of hierarchical comprehensive evaluation. The evaluation process is divided into three steps: first-level index evaluation, second-level index evaluation and comprehensive weight. Analytical Hierarchy Process (AHP) made decisions based on comparative decomposition, comparative judgment and integrated thinking process. It has the advantages of conciseness, systematism and needing less quantitative data. The basic steps include the construction of paired comparison matrices, the calculation of weight vector and the consistency test.

1. First-level index evaluation

(1) Construct the comparison quantization matrix in pairs. First, using expert scoring method compare the first-level indicators in pairs and determine the importance of the ratio between the first indicators, then the comparison matrix A is available:

\[
A = \begin{pmatrix}
\ddots \\
0 & a_{ij} & 0 & \cdots \\
0 & 0 & a_{ij} & \cdots \\
\cdots & \cdots & \cdots & \ddots \\
0 & 0 & 0 & \cdots & a_{ij}
\end{pmatrix}, \quad a_{ij} > 0, \quad a_{ij} = \frac{1}{a_{ji}}, \quad a_{ii} = 1
\] (1)

In which \(a_{ij}\) is the importance comparison of first level index. \(a_{ij}\) and \(a_{ji}\) have a reciprocal relationship between each other. The comparison scaling of importance of evaluation index is shown in Table 1.

| Scale value | Meaning             |
|-------------|---------------------|
| 1           | Of equal importance |
| 3           | Slightly important  |
| 5           | Clearly important   |
| 7           | Strongly important  |
| 9           | Absolutely important|
| 2, 4, 6, 8  | The middle value of the adjudication above |

(2) Calculate the weight vector according to the quantization matrix.

\[
W_i = (\prod_{j=1}^{n} a_{ij})^{1/n} \quad i, j = 1,2, ..., n
\] (2)

\[
W = [W_1, W_2, ..., W_n]^T
\] (3)

Normalize the vector W:

\[
w_i = W_i / \sum_{j=1}^{n} W_j
\] (4)

(3) Consistency check

In order to judge the reliability of paired comparison quantization matrix, it is necessary to test its consistency. First, the consistency index CI is calculated.

\[
CI = (\lambda_{\text{max}} - n) / (n - 1)
\] (5)

In which n is the order of matrix, and \(\lambda_{\text{max}}\) is the largest eigenvalue of matrix A, and there is:

\[
\lambda_{\text{max}} = \sum_{i=1}^{n} \frac{\sum_{j=1}^{n} w_j a_{ij}}{nw_i}
\] (6)
The average random consistency indicator RI is shown in Table 3-2 below.

\[ CR = CI / RI \]  

**Table 2. The average random consistency indicator RI**

| Matrix order | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|--------------|---|---|---|---|---|---|---|---|
| RI           | 0 | 0 | 0.58 | 0.89 | 1.12 | 1.26 | 1.36 | 1.41 |

If CR < 0.1, the consistency of the paired comparison quantization matrix is within the acceptable range; if CR ≥ 0.1, then the judgment matrix parameters need to be properly corrected.

2. Evaluation of the second level index

The evaluation of the second-level index adopts the objective weighting of the improved entropy method.

(1) In order to compare two levels of indicators, the indicators need to be consistent and non-dimensional, when non-dimensionalize the inconsistent evaluation indicators the following steps are necessary:

First, centralized processing.

\[ x' = \frac{x - x^*}{S} \]  

In which \( x^* \), \( S \) are the average value of the observed index \( x \) and the average deviation.

Second, range processing.

\[ x' = \frac{x - m}{M - m} \]  

In which \( m \) and \( M \) are the maximum and minimum of \( x \).

Third, maximize processing.

\[ x' = \frac{x}{m} \quad (m > 0) \]  

Forth, minimize processing.

\[ x' = \frac{x}{M} \]  

Fifth, average processing

\[ x' = \frac{x}{x^*} \]  

The original data matrix is:

\[ X = (x_{ij})_{max} = \begin{bmatrix} x_{11} & \cdots & x_{1n} \\ \vdots & \ddots & \vdots \\ x_{m1} & \cdots & x_{mn} \end{bmatrix} \]  

(2) Calculate the entropy value of the i-th second-level evaluation index as:

\[ e_i = -k \sum_{j=1}^{n} x_{ij} \ln x_{ij} \]  

In which \( k = (\ln m) - 1 \)
(3) Calculate the difference coefficient of the i-th second-level evaluation index:

\[ h_i = 1 - e_i \]  

(15)

(4) Calculate the entropy of the i-th second-level index:

\[ q_i = h_i / \sum_{i=1}^{n} h_i \]  

(16)

(5) Entropy correction and weight determination:

If the maximum value of \( q_i \) \( q_i^* \) > 0.3, then the corrected value is \( q_{i+1}^* = 0.3 \), and other entropy weights need to be fixed:

\[ q_i^* = q_i + \frac{q_i}{\sum_{i=1}^{n} q_i} \times (q_i^* - 0.3) \]  

(17)

In which \( i \neq i^* \), \( i = 1, 2, ..., m \)

The weight is:

\[ q^* = (q_1^*, A_1^*, ..., A_m^*) \]  

(18)

The weight vector of the first level index is \( w = (w_1, w_2, ..., w_n) \) and weight vector of the second level index is \( q = (q_1, q_2, ..., q_m) \), the comprehensive energy evaluation model is:

\[ Z = \sum_{i=1}^{n} w_i \left[ \sum_{j=1}^{m} q_{ij} x_{ij} \right] \]  

(19)

### 3.3. An Example of Evaluating the Interaction Potential of Industrial Users’ Intelligent power consumption

This chapter will take an industrial park in Suzhou for example. Based on the data from high consumption industries, large-scale manufacturing and small-scale manufacturing industries, this section evaluates the potential of three types of users in the park by using the interactive potential evaluation model of industrial users. First the comparison matrix A is available by expert scoring.

\[ A = \begin{pmatrix}
1 & 3 & 4 \\
1/3 & 1 & 3 \\
1/4 & 1/3 & 1
\end{pmatrix} \]

The final three vector weights are: \( w = (0.56, 0.32, 0.12) \). We use the improved entropy method to calculate the weight of the second-level indicators and make the consistent and non-dimensional treatment of the industrial users’ electricity consumption data in the park. The economic indicators after the treatment are shown in Table 3.

| Users | High energy users | Large manufacturing industry | Small manufacturing industry |
|-------|-------------------|------------------------------|-----------------------------|
| \( A_1 \) | 0.25              | 0.25                         | 0.50                        |
| \( A_2 \) | 0.25              | 0.55                         | 0.20                        |
| \( A_3 \) | 0.10              | 0.41                         | 0.49                        |
| \( A_4 \) | 0.41              | 0.41                         | 0.18                        |
According to the weighting steps of improving entropy method, the weight of the second-level index is calculated as shown in Table 4.

| Index | Entropy Value \( e_i \) | Difference Coefficient \( h_i \) | Weight \( q_i \) |
|-------|-----------------|-----------------|----------------|
| A_1   | 0.75            | 0.25            | 0.227          |
| A_2   | 0.72            | 0.28            | 0.255          |
| A_3   | 0.68            | 0.32            | 0.290          |
| A_4   | 0.75            | 0.25            | 0.228          |

The weights of technical and practical secondary indicators of industrial users are calculated by using the evaluation model of interactive potential of intelligent users for industrial users as shown in Table 5.

| Index | Weight |
|-------|--------|
| B_1   | 0.326  |
| B     | 0.397  |
| B_3   | 0.277  |
| C_1   | 0.501  |
| C_2   | 0.169  |
| C_3   | 0.330  |

According to the above indicator weight value, the interactive user potential evaluation model data formula is:

\[
y = 0.127x_1 + 0.142x_2 + 0.162x_3 + 0.128x_4 + 0.104x_5 + 0.127x_6 + 0.089x_7 + 0.06x_8 + 0.02x_9 + 0.04x_{10}
\]

Finally, the integrated value of the interactive potential evaluation of three types of industrial users in the park is shown in Table 6.

From the table above, it can be seen the interactive potentials of the three types of industrial users in the park and the high energy-consuming industrial users have the largest interactive potential while the small-scale manufacturing industries have the smallest potential interactive. By using the comprehensive evaluation model of interactive potential, power grid enterprises can formulate targeted business strategies according to the potential of different types of users.

| Users indicators | High energy users | Large manufacturing industry | Small manufacturing industry |
|------------------|-------------------|-------------------------------|------------------------------|
| A                | 0.136             | 0.229                         | 0.194                        |
| B                | 0.227             | 0.171                         | 0.186                        |
| C                | 0.197             | 0.153                         | 0.146                        |
| Comprehensive evaluation value | 0.56             | 0.553                         | 0.54                         |
4. Conclusion
This paper used a variety of methods to model the interactive potential of industrial users. The model evaluated the interactive potential of industrial users relying on accurate data and information to achieve the optimal allocation of power system resources. It is of great significance to the current energy-saving study and solving the problem of sustainable supply and consumption of clean energy. In the future, the study may extend from industrial users to all users in the city and will provide technical support for the development of integrated smart city response programs. This paper set an interactive evaluation model of industrial user. The main consideration is the index factors directly related to the smart consumption and responses including economic, technical and practical indicators. However, there are some more factors related to the actual smart responses, so in the future, more relevant index factors should be considered so as to make the modeling more realistic.

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