The Research on Modeling Method of Electricity Price Response Characteristics of Large Industrial Users in Spot Market

Gang Wang¹, Haiwei Liu² and Lizhong Xu³

ABSTRACT

Based on the node hourly electricity price in the spot market, the price response characteristics of large industrial users are modeled and analyzed. Under the given node hourly electricity price, the load in each hour of next day is optimized with the goal of minimizing the response cost of large industrial users. The functional relationship of price response under the hourly price is obtained by curve fitting. Taking a typical large-scale industrial user as an example, the model of response characteristics of the large industrial users under hourly price is calculated and obtained with MATLAB, which verified the feasibility of this modeling method.

Keywords: the spot market, large industrial users, node hourly electricity price, response cost.

INTRODUCTION

With the construction of the electricity spot market accelerating, the user-side demand response resources are playing a more and more significant role participating in the market peak shaving. As the main load of user-side, the price response characteristics of large industrial users not only have a significant impact on the overall load characteristics, but also have a strong effect on market price signals and response behaviors. In the future electricity market environment, the spot market and node hourly electricity prices are a very viable market organization and electricity price policy[1-2]. Therefore, it is especially important to deeply study the response characteristics of large industrial users under the node hourly electricity price [3-4].

¹China Electric Power Research Institute, Nanjing, Jiangsu Province, China 210000
²New United Group Co., Ltd, Changzhou, Jiangsu Province, China 213166
³State Grid Zhejiang Electric Power Company, Hangzhou, Zhejiang Province, China 310012

This work is supported by East China Branch of State Grid Corporation Projects of Science and Technology “Research on Design, Development Prospects and Trends of Peak-regulating Ancillary Services Market in East China Branch of State Grid Corporation of China” and State Grid Corporation Projects of Science and Technology “Study on Optimization of Power System Reserve Capacity with Source-Grid-Load Interaction”(52110417001M).
Node hourly electricity price is the marginal cost of providing 1 kWh electricity to users within an hour, considering operational and basic investments [5]. Domestic and foreign scholars have done a lot of work about large users’ price response modeling. Literature [6] proposes a variety of models to describe the dynamic response process of real-time electricity price, and predicted the real-time electricity price response by constructing a predictive model, and revising the forecast results continuously based on the latest load data of response. Literature [7] proposes the HMRDC model to describe the nonlinear process of hourly marginal efficiency based on the LDC mathematical model, and gives the reasonable arrangement of industrial electricity based on the obtained hourly marginal efficiency curve. Literature [8] analyzes the influence of market structure on electricity demand elasticity, and simulates the response behavior of users with coefficient and cross elasticity coefficient.

This paper establishes the non-linear function relationship between output and load of industrial users with a large number of historical data, and optimizes the load value of each period with the goal of maximizing the users’ benefit. Demand response model of large users could be obtained through the curve fitting. Taking a large industrial user as an example, the response function model of hourly price is calculated by MATLAB.

ANALYSIS OF LARGE INDUSTRIAL USERS RESPONSE COST IN SPOT MARKET

According to the existing research results about "source-net-load", the relationship between output and electricity consumption of large industrial user has the following characteristics:

(1) There is a positive correlation between output and electricity consumption, that is, with the increase of electricity consumption, the output also increases.

(2) Considering the full use of the production lines, the greater the total output, that is, the greater the total power consumption, the lower the power consumption per unit of products, so the unit power consumption and total electricity consumption are negatively correlated.

(3) Each large user has its own upper and lower limit of total load in each period.

According to the above points, the relationship curve between output and power consumption can be shown in Figure 1.

![Figure 1. The Curve of the Relationship between Output and Power Consumption.](image)

The curve shown in Figure 1 can be described by function (1).

\[ c(q_t) = a_t(q_t)^2 + b_t q_t + c_t \]  \hspace{1cm} (1)

Where \( q_t \) is the power consumption in period \( t \), \( c(q_t) \) is the production in period \( t \).

Then, the power consumption per unit of products can be described as:
\[
dh = \sqrt[1]{\frac{dc(q_i)}{dq_i}} = \frac{1}{2a_i q_i + b_i}
\]

We can assume that the load is unchanged in an hour, and the corresponding relationship between output and load in each time period can be expressed as:

\[
c(L_t) = a_i (L_t)^2 + b_i L_t + c_i
\]

Where \( L_t \) is the average load after response in period \( t \).

The electricity purchase cost after the price response is shown in function (4).

\[
W_E^t = p_t dh_t(L_t) c_t(L_t)
\]

Where \( p_t \) is the price in period \( t \), \( dh_t \) is the power consumption per unit of products in period \( t \), \( c_t \) is the production in period \( t \).

Then, the cost increases can be shown in function (5).

\[
\Delta W_E^t = p_t dh_t(L_t) c_t(L_t) - p_{0t} dh_t(L_{0t}) c_t(L_{0t})
\]

Where \( L_{0t} \) is the average load before response, \( p_{0t} \) is the original price in period \( t \).

The response cost of large industrial users not only needs to consider the change of the electricity purchase cost, but also the change of the production cost.

Since the marginal cost of production cost is increasing, the production cost \( W_p^t(N^t) \) can be expressed as a concave incremental function. The mathematical expression is:

\[
W_p^t(c_t) = a_2 (c_t)^2 + b_2 c_t + c_2
\]

Then, the additional production cost can be expressed as:

\[
\Delta W_p^t = W_p^t(c_t) - W_p^t(c_{0t})
\]

Where \( c_{0t} \) is the original production in period \( t \).

Then, the cost function of large industrial users after price response is shown as function (8).

\[
W_T = \sum_{t=1}^{24} (\Delta W_E^t + \Delta W_p^t)
\]

THE OBJECTIVE FUNCTION AND CONSTRAINTS

Considering the own benefits of big users, the goal of price responding is to minimize the cost of electricity price response. The objective function is:

\[
\min W_T
\]

For each large industrial user, the maximum load and minimum load are the constraints,
which can be expressed as:
\[ L_{\text{min}} \leq L_i \leq L_{\text{max}} \quad i = 1, 2, \cdots, 24 \]  
(10)

For large industrial users, in addition to the upper and lower load constraints, there is a production constraint, and the constraint refers to the total output constraints, as shown in function (11).
\[ \sum_{i=1}^{24} c_i \geq c_{\Sigma 0} \]  
(11)

Where \( c_{\Sigma 0} \) is the total production daily in original plan.

**EXAMPLES**

From the EMS system of a large industrial user, we select daily production and consumption data of the enterprise in a year for statistical analysis. Select 300 sets of daily output and corresponding electricity consumption data. The production and electricity consumption data can be standardized as follows:
\[ \bar{c}_i = c_i / \left( \frac{1}{300} \sum_{i=1}^{300} c_i \right) \]  
(14)
\[ \bar{q}_i = q_i / \left( \frac{1}{300} \sum_{i=1}^{300} q_i \right) \]  
(15)

Set the daily electricity consumption as the abscissa, and set the corresponding daily output as the vertical axis. The distribution can be drawn in Figure 2.

![Figure 2. The Fitting Curve of the Relationship Between Output and Power Consumption.](image)

It can be seen from the above figure that the distribution of the points is relatively concentrated, and the functional relationship between output and electricity consumption is obtained as shown in formula (16).
\[ c(q_i) = 0.556q_i^2 - 0.479q_i + 0.923 \]  
(16)
Then, the functional relationship between output and load can be described as:

\[ c(L_t) = 0.556L_t^2 - 0.479L_t + 0.923 \]  \hspace{1cm} (17)

The cost increases can be shown as:

\[ \Delta W'_k = p_t(0.556L_t^2 - 0.479L_t + 0.923)/\{1.112L_t - 0.479\} - p_{t_0}(0.556L_{t_0}^2 - 0.479L_{t_0} + 0.923)/\{1.112L_{t_0} - 0.479\} \]  \hspace{1cm} (18)

In order to reduce the impact of additional production cost, this paper sets \( a_2 = 0.1, b_2 = 0.15, c_2 = 0.2 \).

Then, the additional production cost can be expressed as:

\[ \Delta W'_p = 0.1c_t^2 + 0.15c_t - (0.1c_{t_0}^2 + 0.15c_{t_0}) \]  \hspace{1cm} (19)

The cost function of the large industrial users after price response can be shown as:

\[ W_T = \sum_{i=1}^{24}(\Delta W'_k + \Delta W'_p) \]  \hspace{1cm} (20)

The objective function and constraints are shown as follows:

\[ \min W_T = \min \{ \sum_{i=1}^{24}(\Delta W'_k + \Delta W'_p) \} \]  \hspace{1cm} (21)

\[ \begin{cases} \sum_{i=1}^{24} c_i \geq c_{s_0} \\ 0.723 \leq L_t \leq 1.267 \end{cases} \]  \hspace{1cm} (22)

Reference to the hourly price of PJM, the optimal load under day ahead hourly price simulated by MATLAB is shown in Table 1:

<table>
<thead>
<tr>
<th>Period</th>
<th>Price</th>
<th>Load</th>
<th>Period</th>
<th>Price</th>
<th>Load</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.900</td>
<td>1.133</td>
<td>13</td>
<td>1.167</td>
<td>0.943</td>
</tr>
<tr>
<td>2</td>
<td>0.954</td>
<td>1.092</td>
<td>14</td>
<td>1.007</td>
<td>1.080</td>
</tr>
<tr>
<td>3</td>
<td>0.911</td>
<td>1.041</td>
<td>15</td>
<td>1.012</td>
<td>1.056</td>
</tr>
<tr>
<td>4</td>
<td>0.831</td>
<td>1.069</td>
<td>16</td>
<td>0.810</td>
<td>1.003</td>
</tr>
<tr>
<td>5</td>
<td>0.735</td>
<td>1.082</td>
<td>17</td>
<td>0.852</td>
<td>1.014</td>
</tr>
<tr>
<td>6</td>
<td>0.725</td>
<td>1.113</td>
<td>18</td>
<td>1.534</td>
<td>0.783</td>
</tr>
<tr>
<td>7</td>
<td>0.794</td>
<td>0.988</td>
<td>19</td>
<td>1.588</td>
<td>0.736</td>
</tr>
<tr>
<td>8</td>
<td>0.954</td>
<td>0.985</td>
<td>20</td>
<td>1.167</td>
<td>0.965</td>
</tr>
<tr>
<td>9</td>
<td>1.124</td>
<td>0.995</td>
<td>21</td>
<td>1.082</td>
<td>0.917</td>
</tr>
<tr>
<td>10</td>
<td>1.151</td>
<td>0.984</td>
<td>22</td>
<td>0.986</td>
<td>1.022</td>
</tr>
<tr>
<td>11</td>
<td>1.071</td>
<td>1.014</td>
<td>23</td>
<td>0.794</td>
<td>0.986</td>
</tr>
<tr>
<td>12</td>
<td>1.092</td>
<td>1.007</td>
<td>24</td>
<td>0.762</td>
<td>0.992</td>
</tr>
</tbody>
</table>

The distribution of the optimal load and the corresponding hourly price is shown in Figure 3.
In Figure 3, it can be found that the load is negatively correlated with the electricity price. However, since the demand elasticity under different electricity prices is different, the curve cannot be performed by a linear function. The cubic function has a good linearity in a monotone region, and this paper uses a cubic function to perform curve fitting for the scatter points[9-10].

![Fitting Curve of the Relationship Between Load and Price](image)

The curve shown in Figure 3 can be functional described as follows:

$$y = 0.426x^3 - 1.456x^2 + 1.021x + 1.071$$  \(23\)

Then, the responding function of the large industrial user is shown as follows:

$$L_{gi} = \begin{cases} 
0.723L_{avg} & p_i \geq 1.595 \\
(0.426p_i^3 - 1.456p_i^2 + 1.021p_i + 1.071)L_{avg} & 0.526 < p_i < 1.595 \\
1.267L_{avg} & p_i \leq 0.526 
\end{cases}$$  \(24\)

Where \(L_{avg}\) is the basic load.

**CONCLUSION**

This paper optimizes the load of 24 typical time periods with the attention of minimizing the response cost of large customers. Then the response function can be obtained by curve fitting combining the given hourly price and the optimal load of each time period. The modeling method is suitable for large industrial users whose production planning can be flexibly changed. For the large industrial users whose production processes are fixed and cannot be flexibly arranged, the mathematical response modeling remains to be further studied in the future.
REFERENCES


