Study on Economic Efficiency Monitoring Model of Power Grid Enterprises

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**Abstract.** Since 2015, China's economic downward pressure continues to increase. Facing a more complex internal and external environment, power grid enterprises are paying more attention to their business performance. Through the effective monitoring and prevention of potential risks in economic activities, the abnormality of indicators and risk source tracking can realize. It is helpful for the power grid enterprises to find the work short-board and remedy the situation, so as to effectively enhance the competitiveness of the enterprises and adapt them to the new normal.

Here, we firstly studied the benefit decomposition analysis model of power purchasing and selling, we found out the key factors that affected the purchasing and sales electrical benefit. Then, in order to find the abnormality in the electricity business process and trace the reason, we constructed a risk monitoring model of electricity purchasing and selling. In addition, we selected key indicators to be the real-time monitoring objectives. At last, we suggested the power grids to put emphasis upon retail market monitoring.

**Introduction**

As the bridge connecting the power generation side and the power supply side, the power grid enterprises on the hand buy electricity from power generation enterprises, and on the other hand, supply power to the electricity customers. The price difference on both sides, the change of electricity quantity and the mutual influences between the power generation side and the demand side bring quantitative operational risks to the power grid companies \[1\]. In addition, under the new electricity reform, the power grids are facing new challenge because of the inrush of social capitals, the transformation of market mechanism, the distributed generation \[2-4\] and the use of new power equipment \[5\].

At present, there are quite mature researches on the electricity purchasing and selling risks of power grid companies. By using statistical analysis methods such as comparative analysis and factor analysis, experts have conducted penetrating query and linkage monitoring on power purchasing and selling businesses from the aspect of profit, net assets yield and economic value added\[6,7\]. Furthermore, a number of risk optimization control schemes are put forward such as the implementation of peak-valley time-of-use tariff \[8\]. However, there are still many issues to be resolved, like the low level and lack of timely risk monitoring, the inaccuracy of risk measures, the dispersion risk monitoring modules and the short of systematization. Therefore, it is of theoretical and practical significance for power grid
enterprises to further build the electricity purchasing and selling risk monitoring model. Through this model, power grid companies can definite the monitoring indicators, realize intelligent management and improve the economic efficiency.

**Benefit Decomposition Analysis Model of Power Purchasing And Selling**

Purchasing and selling electricity are the main operating activities of power grids. The operation purpose of the power grid enterprises is to obtain the margin between electricity sales revenue and power supply costs, thus to maximize their own benefits. Purchasing and selling electricity benefits can reflect the power grid companies’ break-even situation. It is an important economic indicator to measure their business performance. The benefit Decomposition Analysis Model of Power Purchasing and Selling constructed in this paper is shown in Figure 1:

In this model,

\[ B = R - C_g - C_l \]  

(1)

\( B \) represents purchasing and selling electricity benefits, \( R \) represents power selling income, \( C_g \) represents electricity purchasing cost, \( C_l \) represents cost of line loss.

\[ R = \sum_{i=1}^{104} Q_{si} \times P_{si} \quad i=1,2, \ldots, 1 \]  

(2)
\( Q_{si} \) represents electricity sales of the i-th industry, \( P_{si} \) represents average electricity selling price of the i-th industry.

\[
C_s = \sum_{j=1}^{J} Q_{gj} \times P_{gj} \quad j=1,2,\ldots,J
\]  

\( Q_{gj} \) represents unit on-grid energy, \( P_{gj} \) represents unit feed-in Tariff.

\[
C_l = Q_l \times P_g = \eta \times Q_g \times P_g
\]

\( Q_l \) represents line loss, \( P_g \) represents average electricity purchasing price, \( \eta \) represents line loss rate, \( Q_g \) represents Purchasing power.

\[
Q_s = \sum_{i=1}^{I} Q_{si}
\]

\( Q_s \) represents electricity sales.

\[
P_s = \frac{\sum_{i=1}^{I} Q_{si} \times P_{si}}{Q_s} \quad i=1,2,\ldots,I
\]

\( P_s \) represents average electricity selling price.

\[
Q_g = \sum_{j=1}^{J} Q_{gj}
\]

\( Q_g \) represents purchasing power.

\[
P_g = \frac{\sum_{j=1}^{J} Q_{gj} \times P_{gj}}{Q_g} \quad j=1,2,\ldots,J
\]

\( P_g \) represents average electricity purchasing price.

\[
\eta = \frac{\sum_{n=1}^{N} C_{ln}}{(Q_s + \sum_{n=1}^{N} C_{ln})}
\]

\( C_{ln} \) represents line loss in n-th district.

\[
C_{ln} = \sum_{m=1}^{M} C_{lnm}
\]
\[ C_{lnm} = \frac{Q_{nm}}{1 - \eta_{nm}} - Q_{nm} \]  
\[ (11) \]

\[ Q_{nm} \] represents electricity sales of m-th voltage class in n-th district, \[ \eta_{nm} \] represents line loss rate of m-th voltage class in n-th district.

**Risk Monitoring Model of Electricity Purchasing and Selling**

Based on the decomposition analysis of purchasing and selling electricity business, a risk monitoring model is established in this section to monitor the results of business processes and activities.

**Electricity Purchasing Cost Monitoring**

**Average Electricity Purchasing Price Monitoring.**

Average electricity purchasing price abnormity model:

\[ P_s - \sum_{t=1}^{T} P_{gt} / T \geq 1% \sum_{t=1}^{T} P_{gt} / T \]

\[ (12) \]

In this formula, \( P_s \) represents average electricity purchasing price over the years, \( P_{gt} \) represents average electricity purchasing price in t year.

Average electricity purchasing price threshold model:

\[ P_s - \sum_{t=1}^{T} P_{gt} / T \geq \gamma \sum_{t=1}^{T} P_{gt} / T \]

\[ (13) \]

\[
\begin{align*}
\text{Level 1 warning} & : 2\% \geq \gamma \geq 1\% \\
\text{Level 2 warning} & : 3\% \geq \gamma \geq 2\% \\
\text{Level 3 warning} & : \gamma \geq 3\%
\end{align*}
\]

Through monitoring on the average purchasing electricity price, the abnormity can be timely detected. Then, further monitoring on purchasing power and the unit purchasing electricity power can effectively trace the reason.

**Generating Units Monitoring.**

Changes in the purchasing power are ultimately reflected in the output level and the power distribution of each generating unit. Different types of units contribute differently to the electricity purchasing cost. Differential generations among power units affect the purchasing power as well as power supply reliability, thereby increasing the economic risks of power grid businesses. The weight of electricity purchasing cost per unit accounting for the total electricity purchasing cost is shown as below.
\[
\frac{(Q_{ji} \times P_{ji})}{C_g} = \beta_j \quad j=1,2,\ldots J
\]  

(14)

In this formula, \(Q_{ji}\) represents unit on-grid energy, \(P_{ji}\) represents unit feed-in Tariff. \(C_g\) represents total electricity purchasing cost.

We rank the degrees of the influences of generating units on the electricity purchasing cost from large to small as below:

\[
\beta^{(1)} = \max\{\beta_j | j = 1,2\ldots J\} = \beta_{w_1}, \quad G = \{w_1\}
\]

\[
\beta^{(2)} = \max\{\beta_j | j = 1,2\ldots J, j \notin G\} = \beta_{w_2}, \quad G = \{w_1, w_2\}
\]

\[\ldots\]

\[
\beta^{(J)} = \max\{\beta_j | j = 1,2\ldots J, j \notin G\} = \beta_{w_J}, \quad G = \{w_1, w_2 \ldots w_J\}
\]

According to the influence degrees of the generating units on average purchasing electricity price and the total electricity purchasing cost, the focus of power purchase monitoring successively are: the units with large weights and high prices; the units with large weights but low prices; the units with high prices but small weights; the units with low prices and small weights.

Then, the monitoring emphasis should be the unit \(w_1\), which has the largest impact on electricity purchasing cost.

**Power Selling Income Monitoring**

**Power Selling Income Monitoring Model of Key Industries.**

We use \(i\) to represent each industry and hypothesize that the number of industries in electricity market is \(I\). (Generally, the electricity market is divided into 7 categories of users, such as residential lighting, non-residential lighting, large industrial, non-industrial, commercial, agricultural, and wholesale electricity).

The weight of power selling income of each industry accounting for the total power selling income is shown below:

\[
\frac{(Q_{si} \times P_{si})}{R} = \alpha_i \quad i=1,2,\ldots I
\]  

(15)

In this formula, \(Q_{si}\) represents electricity sales of the \(i\)-th industry, \(P_{si}\) represents average electricity selling price of the \(i\)-th industry, \(R\) represents the total power selling income.

We rank the weight from large to small as shown below:

\[
\alpha^{(1)} = \max\{\alpha_i | i = 1,2\ldots I\} = \alpha_{k_1}, \quad S = \{k_1\}
\]

\[
\alpha^{(2)} = \max\{\alpha_i | j = 1,2\ldots I, i \notin S\} = \alpha_{k_2}, \quad S = \{k_1, k_2\}
\]

\[
\alpha^{(J)} = \max\{\alpha_i | j = 1,2\ldots I, i \notin S\} = \alpha_{k_J}, \quad S = \{k_1, k_2 \ldots k_J\}
\]

So the monitoring emphasis should be the industry \(k_1\), which has the largest impact on power selling income.
Figure 2. Contract of sell electricity revenue weights among industries.

Using the matrix shown above, the trend of power sales weight can be clearly observed. By analyzing the change reason, power grids could see the industries’ tendency and the operating situation of electricity market. Then, an effective management decision could be made.

Electricity Consumption Monitoring of Key Customers

Risks in electricity selling market specifically manifest in the uncertainty of electricity sales, which root in power demand. In order to judge the market trend and draw up marketing strategies, it is extremely helpful to monitor the electricity consumption of key customers.

\[
q_{si} = \frac{\Delta Q_{si}}{Q_{si(t-1)}} = \frac{Q_{sit} - Q_{si(t-1)}}{Q_{si(t-1)}} \times 100\% \tag{16}
\]

\(q_{si}\) represents the change rate of a customer’s power consumption in a statistical time.

\(\Delta Q_{si}\) represents the variable quantity of a customer’s power consumption in a statistical time.

\[
\mu_{si} = \Delta Q_{si} / \sum \Delta Q_{si} = \frac{\Delta Q_{si}}{\Delta Q_{s}} \times 100\% \tag{17}
\]

\(\mu_{si}\) represents the weight of a customer’s power consumption variable quantity accounting for the total electricity sales variable quantity in a statistical time.

\[
\varphi_{si} = \frac{Q_{sit}}{Q_{s}} = \frac{Q_{si}}{\sum Q_{si}} \times 100\% \tag{18}
\]

\(\varphi_{si}\) represents the weight of a customer’s power consumption accounting for the total electricity sales in a statistical time.

\[
\Delta \varphi_{si} = \frac{Q_{sit}}{Q_{s}} - \frac{Q_{si(t-1)}}{Q_{si(t-1)}} = \varphi_{sit} - \varphi_{si(t-1)} \tag{19}
\]

\(\Delta \varphi_{si}\) represents the change rate of the weight of a customer’s power consumption in a statistical time.

By analyzing historical statistic data, we set the reasonable range of electricity sales to \(A\%\), when a customer’s power consumption is out the range of \(A\%\), an electric quantity abnormality occurs.

The risk brought by a single customer’s electric quantity abnormality could be indicated by the multiply of abnormal degree and abnormal frequency.
\[ \zeta = \delta \times f \]  

\[ \delta = \frac{(Q_u - \bar{Q})}{\bar{Q}} \]  

As shown above, \( \zeta \) represents the impact brought by a single customer’s electric quantity abnormality, \( \delta \) represents the abnormal degree, \( f \) represents the abnormal frequency, \( Q_u \) represents electricity sales in a statistical time, \( \bar{Q} \) represents historical average electricity sales in the same period.

Electric quantity abnormality leads to tariff recovery risk. When risk reaches the early warning value, the power grid companies could alert the customer. Furthermore, accumulating the results of all customers in each industry, we can measure the risk of the whole industries.

**On Line Monitoring of Line Loss**

The online monitoring of line loss could be separated into three parts, including data collection, online computation, monitor and alert. Considering the efficiency and safety of power grids, we use the average historical line loss rate \( \bar{f} \) as indicator and set the alert line of the line loss as \( \tau\% \). That means, the model will give an alert when abnormality of line loss rate surpass the average loss rate by \( \tau\% \) (equation 22).

\[ \delta = \frac{(Q_u - \bar{Q})}{\bar{Q}} \]  

To find where the line loss occurs, we propose a cross-locking method (figure 7). Through this method, we could search the problematic point based on the classification of districts and the voltage levels simultaneously. Using the search of the problematic point of the line loss based on the districts as the longitudinal searching, and that based on the voltage levels as the latitudinal searching, the method could cover the whole electrical grids, so that we could find the problem point quickly and contribute to the repair in time, then reduce the loss to the minimum. The concept map of the cross-locking method is as figure 3 shows.

![Figure 3. Concept map of cross-locking method.](image)

Analyzing the data of the ammeter systems by the means of the abnormality of line loss rate, and then finding the problematic point, we could halt the electric-stealing behavior, avoid unnecessary loss, and thereby help the power grids reduce the line loss, approximate the statistical line loss to the theoretical ones, and thus improve the economic efficiencies of the entropies.
Discussion And Suggestions

Using the benefit decomposition model and risk monitoring model of electricity purchasing and selling, the power grids could discover abnormalities in business timely, monitor and prevent marketing risk, and then improve the systematic safety and stability. Especially, under the new electricity reform, the inrush of social capitals with an open electricity retail side, affect the market share of power grids tremendously. The grids should monitor the retail market by classifying industries and electric consumption customers. Digging customer demand thoroughly and providing targeted electricity services, are of great significance for power grid enterprises to maintain their market share and guarantee the economic profits.

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