Research on interruptible load supply curve simulation based on industrial classification

Junshu Feng1*, Bingqi Jiao1 and Jiujin Zhao2

1 State Grid Energy Research Institute Co., ltd, Changping, Beijing, Chin
2 STATE GRID Corporation of China, Xicheng, Beijing, Chin
*Corresponding author’s e-mail: fengjunshu@sgeri.sgcc.com.cn

Abstract. Recently, with the adjustment of industrial structure, peak power load is getting sharper in China. Interruptible Load Management (ILM) enables power system to gain deterministic access to Interruptible Load (IL) provided by power consumers, which can use a more economical way to ensure real-time balance and safe operation of power system. This paper proposes a simulation method of interruptible load supply curve of larger industrial power consumers based on industrial classification, which can predict capacity of interruptible load that larger industrial power consumers are willing to provide under different interruptible load prices. An example towards a China’s eastern province shows that, if government wants to acquire interruptible load capacity of 10 million kW, the interruptible price should be priced higher than 0.7 RMB/kWh.

1. Introduction
In recent years, with the adjustment of industrial structure, peak power load is getting sharper due to increasing proportion of tertiary industry’s power consumption and temperature-related load in China. Specifically, peak load duration of provincial power grid is relatively low, the duration of load exceeding 95% of maximum power load is generally less than 24 hours, and its corresponding power generation does not exceed 0.5% of total annual power generation. The duration of load exceeding 90% of maximum power load is generally less than 168 hours, and its corresponding power generation does not exceed 1% of total annual power generation. In this situation, relying on increasing installed power capacity alone will lead to idling of newly increased system capacity, resulting in low investment efficiency and operation difficulties of power enterprises, which is not conducive to sustainable development of power industry and local economy.

Interruptible Load Management (ILM) enables power system to gain deterministic access to Interruptible Load (IL) provided by power consumers, which can ensure real-time balance and safe operation of power system. This is a more economical way to reduce power system's need for additional increased capacity by cutting down peak loads with very short frequency of occurrence at a less cost.

Due to lack of practical experience of interruptible load in China, bid information of local interruptible load cannot be known to government and power company. Therefore, practical method of estimating interruptible load supply curve comparatively accurately is needed, to support departments of commodity price formulate reasonable interruptible load price and implementation plan, to support departments of energy and power companies for power planning, eventually to achieve lean and intensive development of power industry.
Based on the above background, this paper proposes a simulation method of interruptible load supply curve of larger industrial power consumers based on industrial classification, which can predict capacity of interruptible load that larger industrial power consumers are willing to provide under different interruptible load prices. The reason only choosing larger industrial power consumers instead all industrial power consumers is ILM basically for large users.

2. Supply curve simulation method of interruptible load

Interruptible load supply curve \( F_{IL}(Q_{IL}, p_{IL}) \) is functional relationship between interruptible load price \( p_{IL} \) and interruptible load \( Q_{IL} \), which means total amount of interruptible load that larger industrial power users are willing to provide depending on the interruptible load price that these users being paid when providing interruptible load.

To get accurate interruptible load supply curve of larger industrial users, the best method is to conduct research on each large industrial user, obtain their interruptible power prices and interruptible load capacities, and then accumulate bids of all industrial users to form the interruptible load supply curve of industrial users. However, this method involves such a wide range of work is too hard to achieve.

Therefore, this paper classifies industrial power users according to the industry in which users are located, and accumulatively forms interruptible load supply curve of overall industrial power users by calculating interruptible load price and interruptible load capacity of industrial users in each industry respectively.

Suppose there exists I industries, for industrial users from industry \( i (i=1,2,...,I) \),

2.1. Calculation of interruptible load price

The profit per kilowatt hour of power users refers to added value of profit brought to users by consuming each kilowatt hour of power. Profit per kilowatt hour is used to measure the relationship between power consumption and production profit of power users. This index can reflect the loss of power shortage of users to a certain extent on the premise that interruptible load will not bring damage to equipment and raw materials of users. Therefore, profit per kilowatt hour \( \text{pro}_i \) of industry \( i \) can represent interruptible load price \( p_{IL,i} \) of industry \( i \), which is shown in Equation (1).

\[
p_{IL,i} = \text{pro}_i
\]  

And Equation (2) shows \( \text{pro}_i \) can be calculated by annual profit \( Y_i \) of industry \( i \) divided by annual power consumption \( E_i \) of industry \( i \). And \( Y_i \) and \( E_i \) can be obtained through regional Statistical Yearbook.

\[
\text{pro}_i = \frac{Y_i}{E_i}
\]  

2.2. Calculation of each industries’ interruptible load

The total interruptible load \( Q_{IL,i} \) of industry \( i \) can be simulated according to the industry's annual power consumption \( E_i \) and typical daily power load curve \( b_i(t) \), where \( t=1,2,...,T \) and \( T \) represents time series of daily power load curve. Then, \( Q_{IL,i} \) can be calculated by Equation (3).

\[
Q_{IL,i} = \frac{E_i}{365} \times \alpha_i \times \beta_i
\]  

Where \( E_i/365 \) represents average daily power consumption of industry \( i \), \( \alpha_i \) represents the proportion of large users of industry \( i \) in the total value of industry \( i \) and can be calculated by the proportion of added value of enterprises above scale of industry \( i \) in the total added value of industry \( i \), which can also be found in regional Statistical Yearbook. \( \beta_i \) represents interruptible load coefficient of industry \( i \), which can be calculated by Equation (4).

\[
\beta_i = \begin{cases} 
(b_i(T') - \min(b_i(t)), & b_i(T') - \min(b_i(t)) \geq 0 \\
0, & b_i(T') - \min(b_i(t)) < 0 
\end{cases}
\]
Where $T'$ represents the moment that peak load occurs. Also, typical daily power load curve $b(t)$ should fit Equation (5).

$$\sum_t b_t(t) = 1, \ t = 1,2, \cdots, T$$  \hspace{1cm} (5)

### 2.3. Simulation of supply curve of interruptible load

After obtaining all industries interruptible load bids, which is $\{(Q_{IL,i}, p_{IL,i}), \forall i \in I\}$, rearrange this array according to $p_{IL,i}$ from large to small to a new array $\{(Q'_{IL,i}, p'_{IL,i}), \forall i \in I\}$, where $p'_{IL,i} > p'_{IL,(i-1)}$. Then, by use of Equation (6) to the new array, the large industrial power users' interruptible load supply curve of step type can be formed.

$$F_{IL}(Q_{IL,p_{IL,i}}) = \begin{cases} p'_{IL,1}, & 0 \leq Q_{IL} \leq Q'_{IL,1} \\ p'_{IL,2}, & Q'_{IL,1} < Q_{IL} \leq Q'_{IL,2} \\ \vdots & \vdots \\ p'_{IL,i}, & Q'_{IL,i-1} < Q_{IL} \leq Q'_{IL,i} \\ \vdots & \vdots \\ p'_{IL,J}, & Q'_{IL,J-1} < Q_{IL} \leq Q'_{IL,J} \end{cases}$$  \hspace{1cm} (6)

### 3. Example

Here using an eastern province in China as an example to calculate interprovincial interruptible load supply curve for large industrial power users. The larger industrial power users in this province mainly belong to 32 industries as shown in Figure 1. Then, provincial Statistical Yearbook is used to obtain the total industry profit data of these 32 industries in 2018. Combined with the power consumption data of these 32 industries in 2018, using Equation (2) to calculate profits per kilowatt hour of these 32 industries, as shown in Figure 1.

![Figure 1. Profits per kilowatt hour of 32 industries](image)

The daily load characteristic of this province presents the characteristic of "double peak", and maximum daily load appears around 12:00. After that, Equation (4) can be used to calculate the typical...
daily load curve of 16 industries that meets Equation (5), and interruptible load coefficient of 32 industries can be obtained. Combined these coefficients with power consumption data of 32 industries in 2018 and proportions of the added value of enterprises above the scale in the total added value of 32 industries calculated by using the provincial Statistical Yearbook, total interruptible loads of 32 industries can be calculated by using Equation (3).

After that, Equation (6) is used to calculate the step-type interruptible load supply curve of provincial large industrial power users, as shown in Figure 2.

![Figure 2. Interruptible Load Supply Curve of Large Industrial Power Consumers](image)

Figure 2 shows the relationship between interruptible load capacity and interruptible load price in the example province. For example, if the government wants to acquire interruptible load capacity of 10 million kW, the interruptible price should be priced higher than 0.7 RMB/kWh.

Acknowledgments
This work was supported by State Grid Corporation’s Technological Project of China (Strategic planning and market mechanism research on energy green transition with re-electrification as the core).

References
[1] GEDRA T W. (1994) Optional forward contracts for electric power markets. IEEE Trans on Power Systems, Commun., 9 (4):1766-1773.
[2] Cao S.G., Yang Y.H. and Yu E.K. (1996) Power outage cost and its estimation. Power system technology, Commun., 11:72-74.
[3] Zhang Q., Wang X.F., Wang J.X. (2008) Survey of demand response research in deregulated electricity markets. Automation of Electric Power Systems, Commun., 32(3):97-106.
[4] Ren Z., Kuan X.W., Huang W.Y. (2006) Cost-benefit analysis for actualizing interruptible load measure. Power system technology, Commun., 07: 22-25.
[5] Han Y.M., Chen J., Xiao M.W. (2016) Study on the implementation of demand response in part of pilot cities. Power Demand Side Management, Commun., 18(5):35-37.
[6] Wang M., Shi Y., Jiang Y.Z., Zhang P. (2019) Interruptible Load Compensation Scheme Based on Nash Negotiation Model. Guangdong electric power, Commun., 32(8):51-58.