Evaluation of Reliability and Interruption Cost of Distribution Power System in Industrial Complex

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Abstract - As the power industry moves towards open competition, there has been a call for methodology to evaluate distribution power system reliability by using customer interruption costs. Accordingly, it is increased for methodology to evaluate distribution power system reliability in power supply zones under competitive electricity market. This paper presents algorithm to evaluate system average interruption duration index, expected energy not supplied and system outage cost taking into consideration failure rate of distribution facility and industrial customer interruption cost. Also, to apply this algorithm to evaluate system outage cost presented in this paper, distribution system of a dual supply system consisting of mostly high voltage customers in industrial complex in Korea is used as a sample case study. Finally, evaluation results of system interruption cost, system average interruption duration index and expected energy not supplied in sample industrial complex area are shown in detail.

1. Introduction

In relation to the restructuring of the power industry, service reliability has emerged as a major issue. In addition, severe competition among the energy industry demands energy suppliers to consider the conditions related to service reliability. In other words, as customers have the option to select an alternative energy source in consideration of price, enhancing service reliability is not necessarily a mandatory strategy. Therefore, to effectively deal with such an issue, it is necessary to investigate customers’ response to service reliability and interruption costs. In the past, the issue of service consistency in the power industry was focused on ensuring high reliability at all times. However, as increased costs accompany high reliability, implementing flexible plans for consumers emerging as a new trend within the industry.

For example, if distribution system facilities are expanded, customers will have a stable power supply due to improved service reliability, which is an advantage. However, the facility investment costs incurred will be passed on to customers through increased electric charges, which is a disadvantage. As the improvement of service reliability brings the reduction of interruption costs, it is possible to carry out an economic evaluation of a system facility plan from the consumers' standpoint by quantifying the interruption costs following the changes in service reliability[1]-[3]. Therefore, in Japan and other countries, researchers directed their attention to the evaluation of the service reliability of a power system by taking into account customer interruption costs.

For instance, researchers at Kitami Institute of Technology in Japan suggested a method of evaluating a power system’s service reliability by taking into account the interruption costs[4]. In general, various facilities are used as a distribution power system, including power lines, transformers, and switches. The failure probability of each facility might vary. In addition, the customer interruption costs are varied by customer type. As the method proposed by the researchers at Kitami Institute of Technology does not differentiate these factors and considers them inclusively, accuracy decreases when the interruption cost of a system is calculated. In order to overcome this problem, this paper presents an alternate method involving a methodology to evaluate system average interruption duration index, expected energy not supplied considering failure source and interruption costs by industrial customer type at load point.

For a distribution system, the interruption cost considering interruption duration by industrial customer type was calculated using the amount of unserved energy. A method of totaling the system interruption cost by customer type is then presented. In addition, a new algorithm takes into account the load by customer type and the failure probability by distribution facilities when calculating the amount of unserved energy by industrial customer type.

2. Evaluation of Interruption Costs by Industrial Customer Type

In recent years, to increase the efficiency of the power industry through competition and to ensure customer choice in power purchases the opening of power markets, at home and abroad, has been on the rise. As a result, customer interest in the soundness between electric charges and the level of system reliability has increased. Due to this, when a power company wants to improve its service reliability by reducing interruptions, it is necessary to evaluate how much benefit will be produced. However, as the assessment of customer interruption costs varies from country to country, it is difficult to apply it uniformly. Therefore, in this paper, data of interruption costs by industrial customer type is obtained through survey methodology of Korean customers, conducted by KERI[5]. The amount of expected energy not supplied and the average system interruption time considering the failure source for a sample system were then calculated. Finally, system interruption costs in industrial complex of Korea were evaluated in consideration of customer interruption costs. A summarized flowchart is illustrated in Fig. 1.

Accordingly, in this paper, reliability indices such as system average interruption duration index(SAIDI), system expected energy not supplied due to power outage(EENS), system expected outage cost to customers due to supply outages (ECOST) can be calculated in distribution power system.

2.1 Calculation of system average interruption duration index(SAIDI)

As the failure rate by source, the interruption time for repair and the number of customers experiencing interruption are different, the following equation(1) is used to calculate the system average interruption duration index(SAIDI)

\[
SAIDI = \sum_{i} \sum_{j} t_i \times f_j \times length(number) \times N_j \times N_i \times 60
\]

where, 
\( t_i \) = Interruption duration by outage source i (in minutes) 
\( f_j \) = Rate by outage source i 
\( N_j \) = Number of isolated customer due to outage source i 
\( N_i \) = Total Number of customer
2.2 Calculation of system expected energy not supplied due to power outage (EENS)

In order to calculate system expected unsupplied energy due to power outage, the amount of expected energy not supplied by industrial customer type at load point needs to be calculated. By using the load characteristics by industrial customer type in the load point, the amount of expected energy not supplied is calculated as following equation (2)

$$EENS = \sum \sum L_i \times f_i \times f_i$$

where,
- $i$ = Outage source (power line, transformer, switch, etc.)
- $k$ = Load point
- $L_i$ = Load at load point $k$
- $f_i$ = Interruption duration by outage source i (in minutes)
- $f_i$ = rate by outage source i

2.3 Calculation of system expected outage cost

From the amount of system expected energy not supplied and the estimate of interruption cost by industrial customer type, system total interruption cost based on distribution system configuration is calculated as following equation (3)

$$ECOST = \sum \sum L_i \times C_{ik}(t_i) \times f_i$$

where,
- $i$ = Outage source (power line, transformer, switch, etc.)
- $k$ = Load point
- $L_i$ = Load at load point $k$
- $t_i$ = Interruption duration by outage source i (in minutes)
- $C_{ik}(t_i)$ = Customer interruption cost due to outage source i with interruption duration $t_i$

The following Table 1 presents data of industrial interruption cost per kW by industrial customer type obtained in Korea[5] in 2005 using the detail micro survey procedure.

![Flowchart for the evaluation of system interruption costs considering probability of failure and interruption cost by industrial customer type](image)

**Table 1** Interruption cost for average power consumption according to the interruption duration by industrial customer type

<table>
<thead>
<tr>
<th>Type</th>
<th>Monthly average power consumption (kW)</th>
<th>Interruption cost per average kW (rate: $/kW)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Below</td>
<td>Below</td>
</tr>
<tr>
<td>Textile and apparel</td>
<td>2,233,044</td>
<td>6,451</td>
</tr>
<tr>
<td>Food and beverage</td>
<td>3,003,229</td>
<td>12,806</td>
</tr>
<tr>
<td>Chemicals and chemical products</td>
<td>5,046,603</td>
<td>89,805</td>
</tr>
<tr>
<td>Electric and electronic equipment</td>
<td>1,081,592</td>
<td>80,335</td>
</tr>
<tr>
<td>Food and beverage</td>
<td>43,827</td>
<td>22,783</td>
</tr>
<tr>
<td>Basic/fabricated metal</td>
<td>99,280</td>
<td>12,806</td>
</tr>
<tr>
<td>Other machinery and equipment</td>
<td>107,627</td>
<td>11,594</td>
</tr>
<tr>
<td>Electric machinery</td>
<td>239,658</td>
<td>7,393</td>
</tr>
<tr>
<td>Audio visual equipment</td>
<td>90,041</td>
<td>9,847</td>
</tr>
<tr>
<td>Motor vehicles</td>
<td>306,123</td>
<td>23,669</td>
</tr>
<tr>
<td>Other transport equipment</td>
<td>103,362</td>
<td>9,356</td>
</tr>
</tbody>
</table>

3. 결 론

Methods of evaluating service reliability have been presented, part of which involves a method of evaluating service reliability based on the interruption cost by converting the load customers suffer due to interruptions into currency. In this paper, breaking away from the traditional method of power supply, in which the supplier alone decides the level of acceptable service reliability, a means of supply reliability evaluation reflecting the customers’ side was introduced. In addition, to evaluate the system interruption costs more accurately, the amount of expected energy not supplied by customer type was calculated considering the failure probability by distribution facilities and the evaluation of a customer interruption cost by industrial customer type for service areas defining the total system interruption cost considering interruption duration. Then, the final system interruption cost was calculated by using the interruption cost by industrial customer type.