Evaluation of the Interruption Cost of Distribution Power Systems Considering the Failure Source and the Composite Customer Interruption Cost

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Abstract - As the power industry moves towards open competition, there has been a call for methodology to evaluate power system reliability by using composite interruption cost. This paper presents algorithms to evaluate the interruption cost of distribution power systems by taking into consideration the failure source and the composite customer interruption cost. From the consumer's standpoint, the composite customer interruption cost is considered as the most valuable index to estimate the reliability of a power distribution system. This paper presents new algorithms that take into account the load by customer type and failure probability by distribution facilities while calculating the amount of unserved energy by customer type. Finally, evaluation results of unserved energy and system interruption cost based on composite customer interruption cost are shown in detail.

Keywords: power system reliability, unserved energy, failure probability, composite customer interruption cost

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 is 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 cost, 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][2][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 cost ([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 another method.

Thus, this paper presents a methodology to evaluate composite interruption costs by customer type weighing factors in proportion to interruption duration. For a distribution system, the composite interruption cost considering interruption duration by customer type was calculated using the amount of unserved energy. A method of totaling the composite interruption cost by customer type is then

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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 customer type.

2. Evaluation of System Interruption Cost

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 this will produce. 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 customer type is obtained through macro economic methodology of Korean customers, conducted by KERI. The amount of unserved energy and the average system interruption time considering the failure source for a sample system were then calculated. Finally, system interruption costs were evaluated in consideration of composite customer interruption costs. A summarized flowchart is illustrated in Fig. 1.

2.1 Evaluation of the composite interruption costs

In recent years, the level of power service reliability in advanced countries and Korea has been high. To raise the reliability level even higher the investment necessary to expand power facilities increases drastically. However, the advantages to the customers in regards to improved reliability are not as high compared to the amount of investment necessary because the increase of investment for facility expansion increases the cost of power supply, which in turn causes the increase of electric charges back to customers. From that point, it is not advantageous to customers. Therefore, it is important to plan and operate power facilities balancing the advantages customers will receive, the improved reliability and the cost increase that customers will absorb. In other words, it is necessary to decide the most efficient size of power supply facilities in order to minimize the total cost customers have to pay Actual or perceived costs of interruptions can be utilized to determine the benefit or worth of reliability. A variety of approaches have been used to investigate the cost of power interruption. One approach that is considered to yield acceptable results in an assessment of service interruptions is the customer survey method. The other one is the macro method, which evaluates the interruption cost in relation to the national economy. Studies of these types provide data that can be used to create customer interruption costs. In this paper, the evaluation of a composite for customer interruption costs for service areas is introduced to define the total customer interruption cost for that area as a function of the interruption duration. The composite interruption cost is a function of the various customer type and other variables such as duration of interruption, frequency of interruption, time of interruption (or day), season of interruption and regional difference. These costs are weighted in proportion to their respective power demand within the area. Weighing by the annual peak demand is used for short duration interruptions and weighing by the average demand is used for duration interruptions longer than one-half hour. These costs are then summed to provide the total costs for the area for each duration period. The variation of this total cost with duration is considered to be the composite interruption costs for the service area.

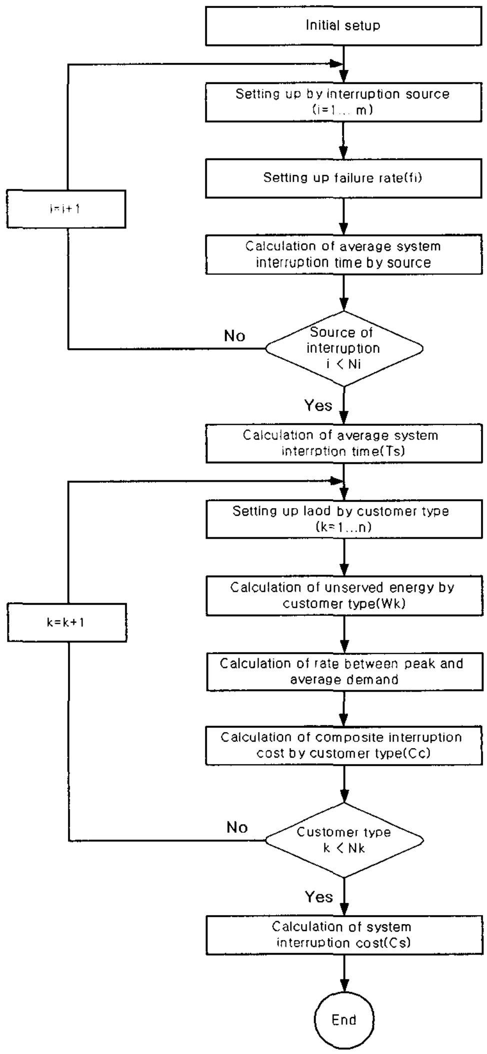

Fig. 1 Flowchart for the evaluation of system interruption costs considering failure source and composite customer interruption cost

Despite the uncertainties affecting the development of composite interruption cost, it is the most suitable tool available in determining monetary estimates of reliability worth. This paper presents methodology to calculate composite interruption costs in a service area, as illustrated in the following equations (1) & (2):

$$C_c = \Sigma\, \alpha_k \;\; C_k \tag{1}$$

where,
k = Customer type
C_k = Interruption cost by customer type (long duration)
α_k= Rate of average demand by customer type (%)
C_c = Composite Interruption cost (long duration)

$$C_c = \Sigma\, \beta_k \;\; C_k \tag{2}$$

where,
k = Customer type
C_k = Interruption cost by customer type (short duration)
β_k= Rate of peak demand by customer type (%)
C_c = Composite Interruption cost (short duration)

The following table shows data of this interruption cost by customer type obtained from KERI.

Table 1 Evaluation for sector customer interruption cost of each failure duration (unit: won)

Customer Type	Interruption Duration				
	1 minute	20 minutes	1 hour	4 hours	8 hours
Residential	14	282	1,758	16,237	48,585
Manufacturing	366	877	1,415	3,216	4,725
Mining	103	486	757	2,824	4,219
Public	35	314	1,266	5,543	22,020
Service	426	1,151	2,861	9,706	20,401
Agriculture & Fisheries	9	820	4,098	34,189	95,659

2.2 Calculation of average system interruption time considering the failure source

As the failure rate by source, the interruption time for repair and the number of customers experiencing interruption are different, the following equation (3) is used to calculate the average system interruption time.

$$Ts = \sum \frac{\mathrm{ti} \times \mathrm{fi} \times \mathrm{Length(Num\,ber)} \times \mathrm{Ni}}{Nt \times 60} \tag{3}$$

where,
i = Failure source (power line, transformer, switch, etc.)
N_i = Number of customers experiencing Interruption by failure source
N_t = Total number of customers
t_i= Interruption time by source (in minutes)
f_i = Failure rate by source

At this time, the average interruption time is calculated in Table 2 with consideration to dispatch time, failure detection time, and average switch changing time.

Table 2 Calculation of average interruption time by source

Number of switches	Number of lines	Number of switches per line	Dispatch time (in minutes)	Average failure detection time (in minutes)	Average switch changing time (in minutes)	Average interruption time (in minutes)
①	②	③ = ①/②	④	⑤	⑥	⑦ = ④+⑤+⑥

2.3 Calculation of the amount of unserved energy

In order to calculate the total amount of unserved energy of a system for the evaluation of service reliability from the customers' standpoint, the amount of unserved energy by customer type needs to be calculated. By using the load characteristics by customer type in the respective area, the amount of unserved energy by customer type is defined by the following equation:

$$W_k = \;P_k \;\times\; T_s \tag{4}$$

where,
k = Customer type
W_k = Amount of unserved energy by customer type
P_k = Load by customer type
T_s = Average system interruption time (h)

2.4 Evaluation of system interruption cost

From the amount of unserved energy (W_k) by customer type and the estimate of composite interruption cost (C_c), the interruption cost of a system according to system configuration is calculated as in the following equation:

$$C_s = \Sigma\, C_c \;\times\; W_k \tag{5}$$

where,
k = Customer type
C_c = Composite customer interruption cost
W_k = Amount of unserved energy by customer type
C_s = System interruption cost

3. A Case Study

3.1 Conditions of case study

To apply the algorithm that evaluates service reliability taking into account the customer interruption cost presented above, a distribution system of a dual supply system consisting of mostly high voltage customers, as shown in Fig. 2, is used. In this study, for the model system shown in Fig. 1, the average system interruption time and the amount of unserved energy by customer type was calculated for the failure by distribution facilities type. The system interruption cost was then evaluated in consideration of the composite interruption cost by customer type.

For distribution systems, related regulations require that loads over 100kW should be supplied by high voltage and loads under 100kW should be supplied by low voltage through transformers. Therefore, in this study, we hypothesized that the model system supplies high voltage of over 100 kW to 8 customers and low voltage of under 100kW to residential customers. In Table 3, load characteristic data including the load amount by switch and customer type are presented.

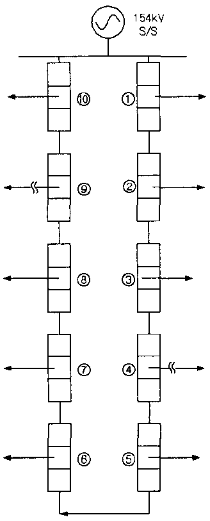

Fig. 2 Configuration of model power system

Table 3 Load Characteristic data of the model power system

Switch Number	Load (kw)	Customer Type
①	800	Public
②	1,500	Service
③	650	Public
④	3,500	Service
⑤	100	Residential
⑥	2,000	Service
⑦	900	Public
⑧	100	Residential
⑨	750	Public
⑩	3,000	Service

3.2 Results of the case study

For the model system, we calculated the average system interruption time in consideration of the failure probability by distribution facilities consisting of power lines, switches, and transformers, by using equation (3) and based on the following assumptions. The results are shown in Table 4.

- The average switch changing time is 3 minutes per switching station. Also, the time taken to move for repair is considered to be 10 minutes (considering the site situation).
- Calculates the number of lines for the system supply method.
- Number of average switch stations = Number of switch stations ÷ Number of lines
- n = (Number of average switch stations ÷ 2^n) ≤ 1
- Average failure detection time = (n - 1) x 10 minutes / per move
- Average switch changing time = (2n - 1) x 3 minutes / per switch station
- Transformer changing time is considered to be 120 minutes.

Table 4 Calculation of system average interruption time

Interruption Source	Failure Rate	Length (Number)	Total Customers	Interruption Time (min.)	Number of Customers Experiencing Interruption (by interruption source)	Number of Customers Experiencing Interruption (annual)	Customer Interruption Time (for the year - min.)	Average System Interruption Time
	①	②	③	④	⑤	⑥=①*②*⑤	⑦=④*⑥	⑧=⑦/③
Lines	0.0129	40	10	24.15	2.5	1.2900	31.1535	3.11535
Switches	0.00145	10	10	24.15	2.5	0.0363	0.8766	0.08766
Trans-formers	0.00145	10	10	120.0	1.0	0.0145	1.7400	0.1740
Total	-	-	-	-	-	1.3408	33.7701	3.3770

By using the average system interruption time calculated with equation (3), the amount of unserved energy by customer type was calculated with equation (4) and the results are shown in Table 5.

Table 5 Calculation of unserved energy

Customer Type	Load (kW)	Number of Customers	Load Per Customer (kW)	Interruption Time Per Customer (Hr)	Unserved energy (kWH)
	①	②	③=①/②	③=Average system interruption time*②/60	⑤=③*③
Public	3,100	4	775	0.225	174.48
Service	10,000	4	500	0.225	562.83
Residential	200	2	100	0.113	11.26
Total	13,300	10	-	-	748.57

In this case study, the rate between peak and average demand in each service area by using load characteristics in the model system is shown in Table 6. The data, presented in Table 6 is calculated with a ratio between peak and average demand in urban areas in Korea. By using the rate between average and peak demand, which is presented in Table 6, composite customer interruption costs by customer type is calculated in equation (1) and equation (2). The results are shown in Table 7.

Table 6 The proportion of average load to peak load for each customer sector

Customer Type	Average Demand (%)	Peak Demand (%)
Residential	16.0	20.0
Manufacturing	36.0	30.0
Mining	18.0	14.0
Public	4.0	5.0
Service	24.0	27.0
Agriculture & Fisheries	2.0	4.0

Table 7 Composite customer interruption cost

Interruption Duration	Composite Customer Interruption Cost (won/kW)	Composite Customer Interruption Cost (won/kWH)
1 minute	244	14,640
20 minutes	747	2,241
1 hour	1,746	1,746
4 hours	7,499	1,875
8 hours	17,944	2,243

Next, to evaluate system interruption cost taking into account the composite interruption cost from the amount of unserved energy calculated in Table 5, the final system interruption cost in each service area was calculated by summing and multiplying the amount of unserved energy and customer interruption cost by customer type. The results are presented in Table 8.

Table 8 Assessment of system interruption cost

Customer Type	Amount of Unserved Energy (kWH)	Composite Interruption Cost Per Customer (won/kWH)	System Interruption Cost (1,000 won/year)
	①	②	③=①*②
Public	174.48	2,241	391.0
Service	562.83	2,241	1,261.3
Residential	11.26	14,640	164.8
Total	748.57	-	1,817.1

4. Conclusion

Methods of evaluating service reliability have been presented. Part of which is a method of evaluating service reliability based on the interruption cost by converting the loss customers suffer due to interruptions into money. 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 method of supply reliability evaluation reflecting the customers' side was introduced. In addition, to evaluate the system interruption cost more accurately, the amount of unserved energy by customer type was calculated considering the failure probability by distribution facilities and the evaluation of a composite customer interruption cost 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 customer type.

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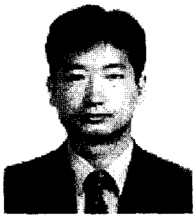

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