Assessment of Interruption Costs for Public Customers

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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 customer interruption costs. This paper presents an evaluation of the interruption costs for public customers in Korea using customer survey methodology. When various research results are examined, the evaluation of direct interruption costs becomes much more simplified. Especially, in the case of public customers, it is known that the evaluation of direct interruption costs is more useful. Accordingly, this paper selected the customer survey method to evaluate the interruption costs for public customers in Korea considering interruption and customer characteristics.

Keywords: Analysis of customer type, customer characteristics, power industry, public customer interruption cost

1. Introduction

Ensuring reliability has and will continue to be a priority for electricity industry restructuring. Reliable electric power delivered on demand is a cornerstone of electricity's ubiquitous adoption and use. A central feature in electricity's value to consumers, whether they are individual households or large industrial complexes, is the infrequent occurrence of outages or other power disturbances that interrupt the use of appliances, motors, electronics, or any of the other myriad of end uses for which electricity is the primary energy source.

While no one disagrees that customers seek reliable power, ensuring reliability is a complex and multi-faceted problem. The strategies available to meet that goal are numerous and the price tags associated with them vary greatly. Most important of all, reliability has always been a shared responsibility because it is a public benefit. Therefore, who pays and who benefits from increased reliability has always been an important question for both private and public decision makers.

The recent August 14th blackout in the Northeast - the largest blackout in U.S. history - has punctuated the importance of and at the same time difficulty in determining the best strategy or combination of strategies.

Accordingly, 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. Nonetheless, 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 have directed their attention to the evaluation of the service reliability of power systems by taking into account customer interruption costs.

Accordingly, the validity of a reliability level appropriate for the operation and establishment of new power systems has become a significant issue. The legitimacy of a rational reliability level can be determined through the benefit assessment of system reliability and the evaluation of customer loss due to a decrease in system reliability level.

The quantification of loss resulting from lowered reliability can heighten the interest in the cost and value of reliability. This will play a crucial role in the planning and operation of future power systems. Even though the evaluation of value according to the different levels of

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system reliability is a more advanced way to fulfill this role, the evaluation of the value of reliability and interruption costs has not yet been soundly established.

The evaluation of customer interruption costs has only recently become an imperative research aspect and the quantification of interruption costs is very complex and subjective. In other words, direct results of interruption are relatively easy to quantify whereas reduced labor efficiency, fear, damage, and loss of daily activities are very difficult to quantify. In addition, indirect impacts such as disorder due to interruption or business transfer to areas with high reliability are more complex to evaluate.

Compared to direct results that have short term effect, indirect results have long term effect and therefore their evaluation is more complicated. Furthermore, the evaluation of such results depends largely on customer characteristics such as customer type, operation size, and amount of power used, as well as on power characteristics, such as interruption duration, interruption frequency and time period. Moreover, it is very complicated to calculate the interruption costs according to the reliability level the customer experienced and the one he/she expects, and the interruption costs following changes in interruption extent, i.e. extensive interruption or local interruption.

The examination of various research results indicates that the evaluation of direct interruption costs is a much simpler method. In the case of commercial customers, it is known that the evaluation of direct interruption costs is more useful. Therefore, this paper presents an examination of the direct and short term interruption costs borne by commercial customers through a survey. The questionnaire included interruption characteristics, such as interruption duration, day, time, and month of interruption, whether an advance warning was given or not, as well as customer characteristics, such as business size and type.

2. Main Discourse

2.1 Evaluation of the system interruption costs

In recent years, the level of power service reliability in advanced countries and Korea is quite high. Accordingly, to raise the reliability level higher than the current level, the investment necessary to expand power facilities has gone up drastically. However, the level of advantage the customers receive from improved reliability is not as high compared to the amount of investment necessary. This is because the rise in investment for facility expansion increases the cost of power supply, which in turn causes the rise in electric charges to the customers. From that point, it is not advantageous to the customers. Therefore, it is important to plan and operate power facilities in consideration of a balance between the advantages the customers will get from the improved reliability and the cost increase the customers should bear. In other words, it is necessary to appropriately determine the size of power supply facilities thereby minimizing the total costs customers are required to pay, which are the sum of power supply costs and the customer interruption costs.

Because it is necessary to establish a plan in consideration of service reliability, it is crucial to review and evaluate the interruption costs from the customers' standpoint. Researches on the evaluation of interruption costs have been carried out in Britain, France, Italy, Canada, the U.S.A and Japan since they were first initiated in Sweden. Various methods have been used to evaluate the interruption costs but they can be classified into two types.

The first type is the macro method, which evaluates the interruption costs in relation to the national economy. The second type is the micro method, which calculates the interruption costs by customer type based on the survey of individual customers.

The former, the macro method, was conceived on the point that economic loss occurs after power interruption as economic activities are halted, that is justifiable economic value is lost due to power interruption. The simplest method is calculating the interruption cost macroscopically by dividing GNP by total power consumption. A more detailed method is also used.

By using tables related to economic activities, this method calculates the interruption costs of each economic sector by dividing the value added obtained in the sector by the power input of the sector. These methods are rough but do have their merits. With these methods, it is possible to calculate the interruption costs of a country as a whole or by sector. However, evaluating the interruption costs of individual customers with the values obtained by these methods does present some problems.

On the other hand, with the latter, the micro method, it is possible to calculate the interruption costs of customer groups but not individual customers. The result can be problematic from an objectivity standpoint. As such, it is necessary to conduct large scale surveys.

Actually interruption costs have been calculated based on large scale surveys in Sweden, Britain, France, the U.S.A, Canada and Japan but there has been no specific evaluation on this in Korea so far. In this paper, we carry out public customer interruption costs using the micro survey evaluation method.

2.2 Elements examined through customer survey

A list of elements that are believed to affect the interruption costs for commercial customers was compiled.

The questions were as simple as possible to minimize

the inconvenience to respondents. The following items were included in the questionnaire.

(1) Interruption characteristics
- Interruption characteristics by area
- Interruption duration and frequency
- Interruption season
- Interruption day
- Interruption time
- Preference for power facility
- Worst interruption period
- Interruption cost change by period

(2) Customer characteristics
- Customer type
- Number of workers
- Average working hour per month
- Area type
- Monthly power use
- Monthly electric fee
- Loss by interruption period
- Having or not having interruption experience

2.3 Design of Questionnaire

For the survey design, the questionnaire developed by Saskatchewan University, Canada was adopted to suit the Korean situation.

The survey questionnaire for public customers developed for this paper is as follows. The questionnaires used by other researches were changed and supplemented as follows.

(1) The method to calculate the interruption cost by interruption time was improved.
(2) Items necessary for the calculation of interruption by interruption duration for public customers were developed.
(3) Items for the calculation of interruption cost by area and customer type were developed.

The questions used for both of the public customers are as follows. The questions included power use amount by area and customer type, emergency power supply device and available supply time, worst interruption month, day, and time, interruption cost change by day and month, rate of interruption cost reduction by interruption warning time, and the size and number of workers by area and customer type. One of the most important tasks in the design of the questionnaire was to make an annual list of interruption cost changes by month, a weekly list of interruption cost changes by day and a daily list of interruption cost changes by time.

For this purpose, a Friday case was set as the base and respondents were asked about interruption cost changes. The respondents were able to record rational interruption cost changes for each question item for this base case.

2.4 Survey Procedure

The survey procedure included selection of samples by area, site visit and survey implementation, collection of power use data, and data analysis.

The power company randomly selected samples in consideration of regional distribution of samples, visited them, and carried out the survey.

2.5 Target areas for the survey of public customers

500 customers were selected in consideration of public customer type distribution.

- Financing Organization : 100
- Sports Organization : 100
- Educational Organization : 100
- Medical Organization : 100
- Government Organization : 100

2.6 Analysis of interruption characteristics

Public customers were classified into financing organizations, security exchange organizations, sports organizations, educational organizations and medical organizations. Classification was done to calculate the interruption costs more accurately by public customer type.

2.6.1 Analysis of customer type

Table 1 shows customer types of public customers. As can be seen in Table 1, public customers were classified into financing organization, security exchange organizations, sports organizations, educational organizations and medical organizations largely.

Table 1 Customer type of public customers

No	Customer type	Details
1	Financing organizations	Financing companies, stock exchanges, information and communication companies
2	Sports organizations	Gyms, swimming pools and stadiums
3	Educational organizations	Schools and libraries
4	Medical organizations	General hospitals, clinics and pharmacies.

2.6.2 Importance of electric facility and characteristic of emergency power supply device

This survey also examined the importance of various electric facilities and the available power supply time of emergency power supply devices. Table 2 presents the results of the question concerning the importance of electric facility for public customers. Table 3 indicates the results of the question regarding characteristics of emergency power supply devices. The devices ranked in order of importance to public sector customers were interior lighting, air conditioning, exterior lighting, refrigeration/cooling, computers and ventilation devices. As for emergency power supply devices, 70.7% of the public sector customers have emergency power supply devices as shown in Fig. 1. By device type, motor generators were owned mostly by sports organizations followed by medical organizations, government organizations, educational organizations and financing and security exchange organizations. Whereas battery systems were owned mostly by educational organizations followed by financing and security exchange organizations, sports organizations, and medical organizations.

2.6.3 Opinions on interruption and safety

Most of the respondents replied as follows. Fig. 2 and Fig. 3 display number of interruptions experienced during 1 year and the number of interruptions experienced above 1 hour during 1 year. Fig. 4 also shows the number of momentary interruptions experienced during 1 year.

As presented in Fig. 2, Fig. 3 and Fig 4, 41.1% of public customers reported the number of interruptions experienced during the past 1 year was "none". 14.5% experienced interruption that lasted over 1 hour more than once. Overall 88.3% experienced momentary interruption, 29.1% experienced it once and 59.2% experienced it more than twice.

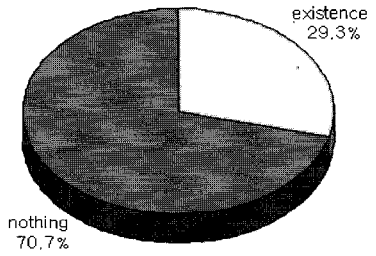

Fig. 1 Existence of emergency power supply devices

Table 2 Importance of electric facility

Rank	Electric facility	Average (100 points)
1	Office facility	95.1
2	Special facility	84.2
3	Building service facility	83.1
4	Individual work environment facility	80.7
5	Employee support facility	65.0

Table 3 Emergency power supply device ownership by organization type

Organization type	Battery system (%)	Motor generator (%)
Financing and security exchange organization	85.2	18.5
Sports organization	40.0	100.0
Educational organization	87.5	37.5
Medical organization	35.7	92.9

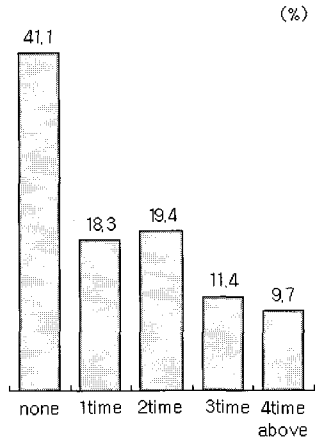

Fig. 2 Number of interruptions experienced during 1 year

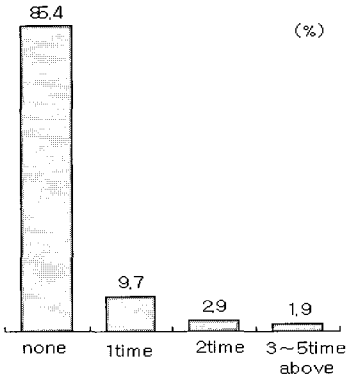

Fig. 3 Number of interruptions experienced above 1 hour during 1 year

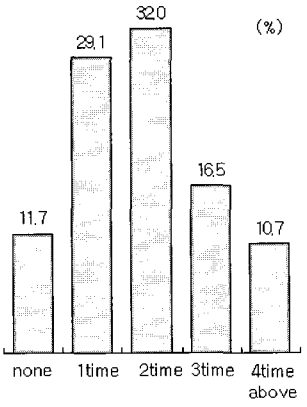

Fig. 4 Number of momentary interruptions experienced during 1 year

2.7 Methodology to evaluate public interruption costs by customer type

This clause analyzes interruption cost changes by period and estimates interruption costs by hour and interruption costs by power use according to customer type.

2.7.1 Analysis of interruption cost changes by period

To find out the interruption cost of worst time period and to discover its change by month, day, and time, it was assumed that an hour of interruption occurs during each period.

Fig. 5 through Fig. 7 show interruption cost changes by month, day, and time for public customers.

In the case of public customers, there was only slight difference by month, day and time, and most respondent's answers showed the interruption costs of every month as similar.

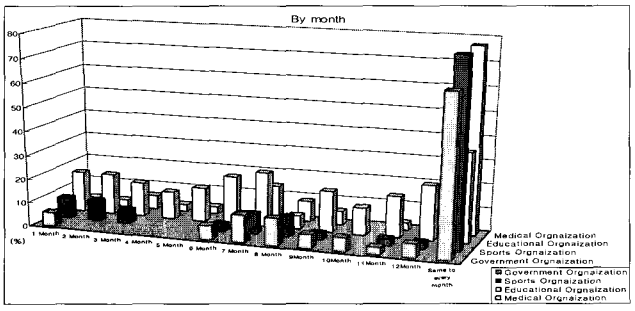

Fig. 5 Interruption cost changes by month

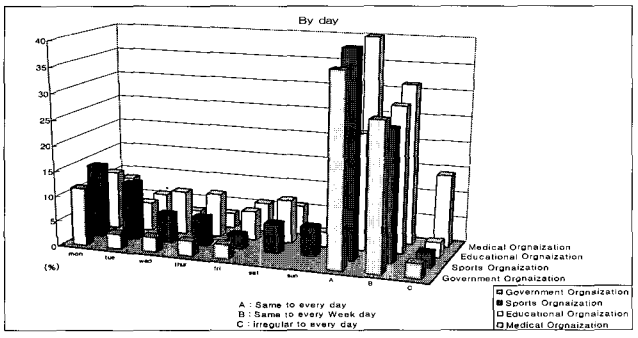

Fig. 6 Interruption cost changes by day

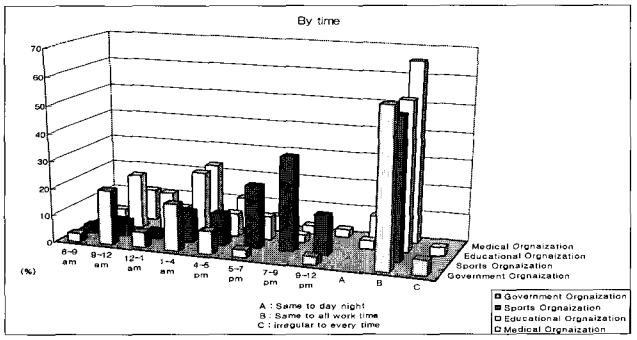

Fig. 7 Interruption cost changes by time

2.7.2 Estimation of interruption costs by interruption duration

Each respondent answered under the assumption that interruption with an unknown date and time would occur.

The respondents were asked to calculate the loss resulting from interruption for the operation of organizations. Interruption costs for 1 minute, 20 minutes, 1 hour and 4 hours were examined.

The respondents were asked to classify the loss into production loss, sales loss, extra labor cost, production restart cost, damage of perishable goods, and other loss. If it was difficult to divide it, then the sum was requested. Table 4 indicates the interruption costs by interruption duration and business type for public customers.

As for public customers, the analysis of interruption costs by business type and interruption duration revealed that the interruption costs were the highest for financing organizations followed by stock exchange organizations, sports organizations, medical organizations and educational organizations.

Table 4 Interruption costs by interruption duration and business type

Average	Interruption duration [won]			
	1 min	20 min	1 hour	4 hours
Financing organization	1,490,000	6,810,000	12,490,000	29,440,000
Sports organization	1,180,000	2,000,000	4,230,000	9,240,000
Education organization	720,000	2,070,000	3,280,000	5,710,000
Medical organization	1,230,000	2,640,000	5,680,000	17,120,000

2.7.3 Estimation of interruption costs per power use by interruption duration

Generally, methods for calculating interruption costs include indirect method and direct method and the latter is more appropriate for the calculation of interruption costs. However, in the case of residential customers, it was difficult to calculate the loss resulting from interruption directly. As a result, an indirect method of considering the amount paid for benefits(preparative action) and substituting benefits (reliability) was used.

For public customers, the direct estimation of interruption costs that combine direct loss according to interruption duration, such as production, sales, and extra labor costs, was used. Therefore, the estimation of customer interruption costs according to the direct loss resulting from interruption is most meaningful to public customers. Table 5 presents the power use by month by customer type for public customers.

The following assumptions were made to correct the interruption costs by interruption duration shown in Table 4 and the power use by customer type shown in Table 5.

- 86%, the statistical data given by the Korea Electric Power Corp for 2003, was used as the daily load factor of average load against maximum daily load for all customer types.
- The maximum load time period was used for the calculation of interruption costs for public customers.

Table 5 Average power use of public customers

	Power use by month[kWh/Month]			
	Financing organization	Sports organization	Educational organization	Medical organization
Average	32,901	11,657	14,206	39,520

Average power use and interruption cost per power use according to interruption duration for public customers was then calculated following equation 1 and equation 2 respectively.

$$Average\ power\ use = \frac{Power\ use\ by\ month}{720} \quad (1)$$

$$Interruption\ cost\ by\ power\ use = \frac{Interruption\ cost\ by\ hour}{Average\ power\ use} \times Load\ factor \quad (2)$$

The result of the interruption costs per power use by interruption duration for public customers is shown in Tables 6 through 9. As well, Fig. 8 gives a comparison of the estimate of interruption costs by public customer type obtained by this study

Table 6 Customer Interruption cost in Financing Organization

	Interruption cost by hour (won)	Average power use [kW]	Interruption cost by power use [won/kW]
1min	1,490,000	32,901	28,042
20min	6,810,000	32,901	128,165
1hour	12,490,000	32,901	235,063
4hour	29,440,000	32,901	554,064

Table 7 Customer Interruption cost in Sports Organization

	Interruption cost by hour (won)	Power use by month [kW]	Interruption cost by power use [won/kW]
1min	1,180,000	11,657	62,680
20min	2,000,000	11,657	106,238
1hour	4,230,000	11,657	224,694
4hour	9,240,000	11,657	490,822

Table 8 Customer Interruption cost in Educational Organization

	Interruption cost by hour (won)	Power use by month [kW]	Interruption cost by power use [won/kW]
1min	720,000	14,206	31,383
20min	2,070,000	14,206	90,226
1hour	3,280,000	14,206	142,966
4hour	5,710,000	14,206	248,883

Table 9 Customer Interruption cost in Medical Organization

	Interruption cost by hour (won)	Power use by month [kW]	Interruption cost by power use [won/kW]
1min	1,230,000	39,520	19,272
20min	2,640,000	39,520	41,364
1hour	5,680,000	39,520	88,994
4hour	17,120,000	39,520	268,236

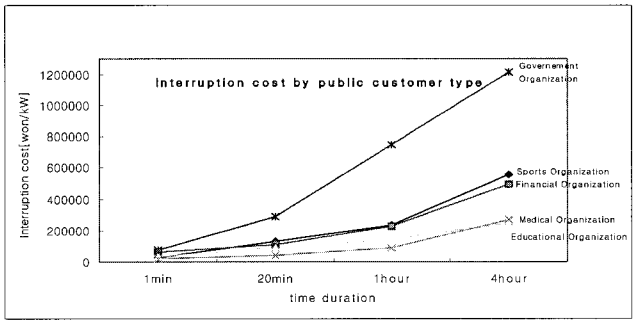

Fig. 8 Comparison of interruption costs by public customer type

3. Conclusion

This paper evaluates the interruption costs for public customers in Korea. While assessing customer interruption costs, the importance of the electric facility, characteristics of emergency power supply use and interruption cost changes by period were analyzed statistically.

The proposed major contents to evaluate public customer interruption costs are summarized as follows. First, we present a method to evaluate production, sales and extra labor costs respectively, which is incurred from interruption duration. Secondly, we present methodology to evaluate interruption costs per power use according to interruption duration by public customer type. To acquire this, we use interruption costs by hour, load factor and power use by month and customer type.

Through survey study, it is concluded that the proposed evaluation methodology can be used to evaluate interruption costs of other customer types with the exception of residential customers.

References

[1] R. Billinton, J. Oteng-Adjei, R. Ghaja, "Comparison of Two Alternative Methods to Establish an Interrupted Energy Assessment Rate", IEEE, Trans. on Power Systems, Vol. PWRS-2, No. 3, August 1987.

[2] M. J. Sullivan, "Interruption Costs, Customer Satisfaction and Expectations for Service Reliability",

IEEE Trans. on Power Systems, Vol. 11, No. 2, May 1996.

[3] Koichi Nakamura, Susumu Yamashiro, "A Survey Study on Estimation of Customer Interruption Costs", T. IEE Japan, Vol. 119-B, No. 2.

[4] Arun P. Sanghvi, "Measurement and Application of Customer Interruption Cost/Value of Service for Cost-Benefit Reliability Evaluation: Some Commonly Based Issues", IEEE Trans. on Power Systems, Vol. 5, No. 4, Nov. 1990.

[5] K. Nakamura, S, Yamashiro, "A Survey Study on Estimation of Customer Interruption Costs", T. IEE Japan, Vol. 119-B, No. 2.

[6] N. Balu, M. Lauby, "Cost-Benefit Analysis of Power System Reliability: Determination of Interruption Costs", EPRI EL-6791s Vol. 1-3, 1990.

[7] S. Yamashiro, K. Nakamura, O. Terada, Y. Tomaki, "Residential Cost of Power Service Interruption-Recent Survey Application to Transmission Planning-", ICEE, Proceedings of the International Conference on Electrical Engineering, Vol. 1, August 1996.

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