산업단지내 배전계통의 공급신뢰도 및 정전비용 평가

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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 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 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 indes(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)

$$SAIDI = \sum_i \sum_j \frac{t_i \times f_i \times length(number) \times N_j}{N_t \times 60} \tag{1}$$

where,

i = Outage source (power line, transformer, switch, etc.)

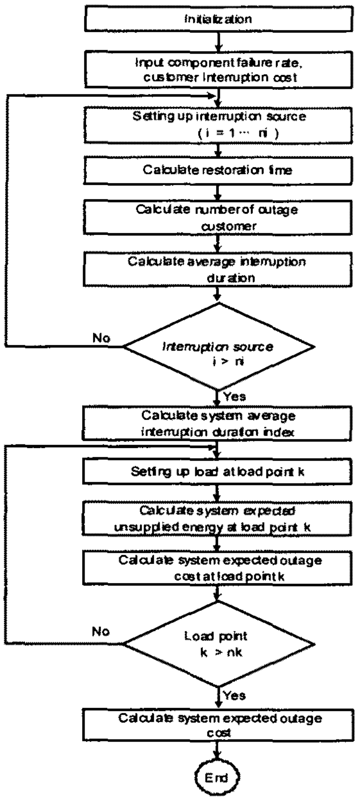
j = Customers experiencing interruption by outage source

Nj = Number of isolated customer due to outage source i

Nt = Total Number of customer

ti= Interruption duration by outage source i (in minutes)

fi =rate by outage source i



<Fig 1> Flowchart for the evaluation of system interruption costs considering probability of failure and interruption cost by industrial customer type

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)

$$EENS = \sum_i \sum_k L_k \times t_i \times f_i \tag{2}$$

where,
i = Outage source (power line, transformer, switch, etc.)
k = Load point
L k = Load at load point k
ti= Interruption duration by outage source i (in minutes)
fi =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)

$$ECOST = \sum_i \sum_k L_k \times C_{ik}(t_i) f_i \tag{3}$$

where,
i = Outage source (power line, transformer, switch, etc.)
k = Load point
L k = Load at load point k
ti= Interruption duration by outage source i (in minutes)
fi =rate by outage source i
Cik(ti) = Customer interruption cost due to outage source i with interruption duration ti

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.

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

Type	Monthly average power use(kWh)	Interruption cost per average kW (unit : $/kW)			
		3sec below	1min below	5min below	30min below
Textile and apparel	1,233,844	8.421	8.724	9.500	13.935
Pulp and paper products	3,093,209	1.650	1.678	1.781	2.100
Chemicals and chemical products	5,046,603	39.806	50.284	52.042	61.505
Electric and electronic equipment	1,087,592	80.335	120.718	174.493	230.076
Food and beverage	43,927	22.783	44.747	78.020	128.504
Basic/fabricated metal	69,283	12.886	18.706	33.359	63.288
Other machinery and equipment	107,437	11.594	15.950	26.605	59.443
Electric machinery	158,957	7.700	13.634	21.470	45.794
Audio visual equipment	94,041	9.647	12.709	23.045	53.517
Motor vehicles	184,107	23.699	36.683	49.706	83.612
Other transport equipment	103,562	9.316	12.862	15.782	39.420

Type	Monthly average power use(kWh)	Interruption cost per average kW (unit : $/kW)			
		1hour below	4hour below	8hour below	8hour above
Textile and apparel	1,233,844	16.952	22.881	34.388	39.768
Pulp and paper products	3,093,209	2.619	9.017	15.381	22.055
Chemicals and chemical products	5,046,603	70.181	84.372	98.950	115.854
Electric and electronic equipment	1,087,592	229.500	299.389	405.556	430.514
Food and beverage	43,927	182.430	410.426	896.906	1,103.595
Basic/fabricated metal	69,283	111.716	210.649	420.882	554.733
Other machinery and equipment	107,437	106.757	229.865	399.013	619.161
Electric machinery	158,957	86.786	226.114	388.452	604.103
Audio visual equipment	94,041	92.411	215.753	337.946	448.962
Motor vehicles	184,107	120.061	206.528	351.617	560.296
Other transport equipment	103,562	66.047	142.871	253.682	298.673

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 loss 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 typefor 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.

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