순간정전을 고려한 배전계통에서의 신뢰도 평가-몬테카를로 방식의 적용

論 文
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Reliability Evaluation of Power Distribution Systems Considering the Momentary Interruptions-Application of Monte Carlo Method

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Abstract - In this paper, we propose a reliability evaluation method considering the momentary interruptions of power distribution systems. The results of research are concentrated on two parts. One is the analytic and probabilistic reliability evaluation of power distribution system considering the momentary interruptions and the other is the reliability cost evaluation that unifies the cost of sustained and momentary interruptions. This proposed reliability cost evaluation methodology is also divided into the analytic and probabilistic approach and the time sequential Monte Carlo method is used for the probabilistic method. The proposed methods are tested using the modified RBTS (Roy Billinton Test System) form and historical reliability data of KEPCO (Korea Electric Power Corporation) system. Through the case studies, it is verified that the proposed reliability evaluation and its cost/worth assessment methodologies can be applied to the actual reliability studies.

Key Words: Reliability assessment, reliability cost evaluation, power quality, Monte Carlo method, momentary interruptions

1. Introduction

The goal of reliability evaluation of power distribution systems is to predict the service security of electric customer based on the topology and information of system components. It has been mainly determined by the frequency and duration of sustained interruption. In resent, the damage of short duration voltage disturbances has been progressively increased because the electronic and precision devices are used in customer-side and the topology of distribution systems becomes shorter and more high dense. Above of all, momentary interruptions occur more frequently than sustained interruptions, and the adverse effects of the former on certain customers are also greater than those of the latter.

Up to these date, the methodology of reliability evaluation for power distribution system is divided into the evaluation of system reliability indices (customer-oriented indices and energy-oriented indices) and the reliability cost/worth evaluation. These two parts can be evaluated into the analytic and probabilistic method. The analytic method is used to decide the average value or expected value of system reliability [1] and the probabilistic method is used to decide the probability distribution of them [2-4]. The reliability indices on power distribution system that had been used in utilities have not been authorized to a standard until the 1990's. The reliability indices, which contain the momentary interruptions on power distribution system, is integrated to the IEEE Standard 1366-1998 [5]. MAIFI (Momentary Average Interruption Frequency Index) and $MAIFI_E$ (Momentary Average Interruption Event Frequency Index) that is related to the momentary interruption are proposed. Studies of momentary interruptions are concentrated on the reduction of the number of occurrence and the development of evaluation methods. Warren [6] studies the method converting the effect of momentary interruptions to sustained interruptions on distribution systems. Brown [7,8] presents the method to determine the impact of momentary interruptions.

The evaluation parameters of conventional reliability methods did not consider the frequency and duration of momentary interruptions. For the case of MAIFI and $MAIFI_E$, it can be hardly applied to actual distribution systems because it needs a specific evaluation methodology.

In this paper, a new reliability evaluation methodology to facilitate a quantitative evaluation of momentary interruptions and its damage in a power distribution system is proposed. The main contents of this paper compose three parts and it is summarized as follows. Section 2 outlines the occurrences and characteristics of

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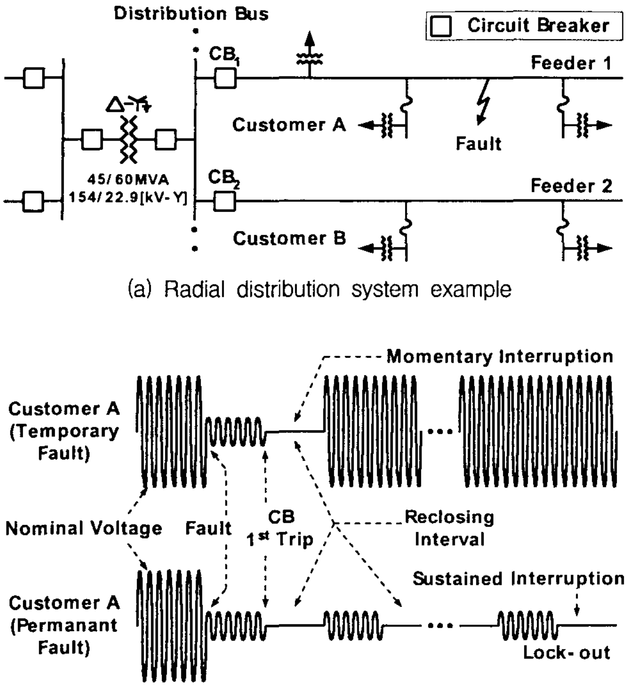


(a) Radial distribution system example

(b) Voltage waveform of faulted feeder customer

Fig. 1 Distribution system model and voltage waveform during fault clearing

sustained and momentary interruptions in a power distribution system and the proposed reliability evaluation method of momentary interruptions are summarized. In Section 3, the unified reliability cost evaluation method that considering the sustained and momentary interruptions is proposed. In Section 2 and 3, the proposed evaluation methods are divided into the analytic and probabilistic approaches and the time sequential Monte Carlo simulation is used for the probabilistic method. In Section 4, we examine the case studies using the modified RBTS (Roy Billinton Test System) and historical reliability data in KEPCO (Korea Electric Power Corporation).

2. Mechanism of Momentary Interruption and Reliability Evaluation of Distribution Systems

In this section, we examine the behavior of sustained and momentary interruptions and propose the analytic and probabilistic evaluation methodology of momentary interruptions.

2.1 Mechanism of Momentary Interruption

The power supply system can only control the quality of the voltage. It has no control over the currents that particular loads might draw. Therefore, the standards in the power quality area are devoted to maintaining the supply voltage within certain limits and the power quality problems are concentrated to the area of voltage quality [9]. The representative voltage quality phenomenon of distribution system is a interruption. Interruptions (sustained and momentary) are usually associated with a fault somewhere on a distribution system. When a fault occurs as shown in Fig. 1(a), the circuit breaker CB_1 opens to clear the fault and automatically recloses after a time delay. This reclosing behavior can take place several times in an effort to establish continuous service for a temporary fault. If the fault is temporary in nature, a reclosing operation on the breaker should be successful and the interruption will only be temporary. The customer ***A*** on faulted feeder experiences a momentary interruption. However, if it is the permanent fault, reclosing operations on the breaker should be failed and the reclosing device will be locked-out. The customer ***A*** on faulted feeder experiences a sustained interruption. As shown in this example, the momentary interruptions are originated to the reclosing behaviors by protective devices, and the reclosing dead-time is the direct source of momentary interruptions.

2.2 Reliability Evaluation of Distribution Systems

The methodology of distribution system reliability evaluation is generally divided into the analytic and probabilistic method. The analytic method is used to decide the average or expected value and the probabilistic methods can be applied to decide the probability distribution of its impact. The average values of each load point or feeder can be used to compare the magnitude of potential risk. However, the probability distributions are very important because the planners need the data of the most severe case.

2.2.1 Reliability Evaluation of Sustained Interruptions

The basic parameters of conventional reliability evaluation are divided into the average permanent failure rate, average permanent outage time, and average annual permanent outage time [1]. Although the three primary indices are fundamentally important, they do not always give the complete solution of the system performance. In order to reflect more actual system severity than them, additional reliability indices are used. The additional reliability indices that are called to the SAIFI, SAIDI, CAIFI, CAIDI, ASAI, ASUI, and etc. are defined in [5].

According to the survey result of the EPRI project [1], the frequency of use for SAIFI, SAIDI, and ASAI (ASUI) is much larger than the others. For the case of CAIFI is relatively small frequency because this index need an additional data compared with SAIFI, SAIDI, and ASAI. For this reason, the SAIFI and SAIDI is used to evaluate the distribution system reliability due to a sustained interruptions. The analytic and probabilistic reliability evaluation of sustained interruptions are summarized in [10].

2.2.2 Proposed Reliability Evaluation Methodologies of Momentary Interruption

(1) Basic Parameters of Momentary Interruption

In this paper, two basic parameters for reliability evaluation of momentary interruptions are defined. One is the average temporary failure rate, λ_M. λ_M for a load point i is

$$\lambda_{Mi} = \sum_{j \in M(i)} \lambda_{Mj} \quad f/yr, \tag{1}$$

where λ_{Mj} denotes the temporary failure rate of a section j and $j \in M(i)$ means the all sections due to occur a momentary interruption for a load point i. The other is the duration of momentary interruption. As mentioned in Section 2.1, it is directly related to the reclosing dead-time. In the successive momentary interruptions due to the reclosing behavior, it is assumed that has the longest one of the several durations [11].

$$t_{Mi} = Max(t_{r_1}, t_{r_2}, t_{r_3}, \ldots\ldots, t_{r_n}). \tag{2}$$

Here, t_{Mi} denotes the duration of momentary interruption and t_{r_n} is the nth reclosing dead-time due to a protective device (circuit breaker or recloser).

(2) Reliability Indices of Momentary Interruption

The two basic indices of momentary interruption are defined in the IEEE Std 1366(1998). One is momentary interruption and the other is momentary interruption event. The each definition is as follows:

- Momentary average interruption frequency index, MAIFI: Single operation of an interrupting device that results in a voltage zero is individually counted. For example, two breaker or recloser operations equal two momentary interruptions.
- Momentary average interruption event frequency index, MAIFI$_E$: If a recloser or breaker operates two, three, or four times reclosing and then lock-out, the event shall be considered one momentary interruption event.

Above indices did not contain the specific evaluation methodologies using the historical reliability data of distribution systems. Therefore, two methodologies for the reliability evaluation of momentary interruptions are proposed. They are also divided into the analytic and probabilistic method, and the time sequential Monte Carlo is used for the probabilistic method.

(3) Proposed Analytic Technique for the Evaluation of Momentary Interruption

The analytical reliability evaluation of momentary interruption is used to decide the potential risk of momentary interruption using the average temporary failure rate(λ_M). The typical process of analytical reliability evaluation method of momentary interruption summarizes as follows.

Step 1) Survey the data of system topology: The line lengths and protective device types in sample system should be collected and the average temporary failure rates of each component are calculated.

Step 2) Calculate the reliability parameters of each load point reliability parameters calculate: The average temporary failure rate of each load point is calculated. For this procedure, the operation schemes of system components and the type and characteristics of devices should be considered.

Step 3) Calculate the system reliability indices: The values of distribution reliability indices (MAIFI, MAIFI$_E$) are calculated as following equations.

$$MAIFI = \frac{\sum_{i=1}^{N_{LP}} N_{Mi} N_{C_i}}{\sum_{i=1}^{N_{LP}} N_{C_i}} = \frac{\sum_{i=1}^{N_{LP}} \left(\sum_{k=1}^{N_r} (\lambda_{Mi} \times P_{r_k} \times k) \right) \times N_{C_i}}{\sum_{i=1}^{N_{LP}} N_{C_i}} \quad int/cus \cdot yr, \tag{3}$$

where N_{Mi} and N_{C_i} are the number of momentary interruptions and customers for load point i. N_{LP} denotes the number of load point of a system. λ_{Mi} is the momentary failure rate for load point i and P_{r_k} denotes the probability of kth reclosing successful. N_r is the number of reclosing attempts.

$$MAIFI_E = \frac{\sum_{i=1}^{N_{LP}} N_{MEi} N_{C_i}}{\sum_{i=1}^{N_{LP}} N_{C_i}} = \frac{\sum_{i=1}^{N_{LP}} \lambda_{Mi} N_{C_i}}{\sum_{i=1}^{N_{LP}} N_{C_i}} \quad int/cus \cdot yr, \tag{4}$$

where N_{MEi} is the number of momentary interruption events for a load point i.

(4) Proposed Monte Carlo Simulation for the valuation of Momentary Interruptions

The process used to evaluate the distribution system reliability related to the momentary interruption indices using time sequential simulation consists of the following steps:

Step 1) Generates a random number for each element and convert it into the TTTF (time to temporary failure) using the probability distribution function of the element.

Step 2) Determines the section with minimum TTTF.

Step 3) For the section with minimum TTTF, generates a random number and convert this number into the reclosing scheme (reclosing success (1^{st}, 2^{nd},) or failure)

Step 4) Records the temporary failure and the momentary outage duration (reclosing dead time) of a load point that is affected with the failed section.

Step 5) Repeats *Step 4* for all load points

Step 6) Generates a new random number for the repaired section and convert it into a new TTTF, and return to *Step 2* if the simulation time is less than one year, otherwise, go to *Step 7*.

Step 7) Records the number and duration of momentary interruptions for all load points that are affected by the failed sections for a year.

Step 8) Calculate the system indices (MAIFI, $MAIFI_E$) and record these system indices for a year.

Step 9) If the total simulation time is less than the specified simulation years, go to *Step 2*, otherwise, go to *Step 10*.

Step 10) Calculates the average number and duration of momentary interruptions for all load points.

Step 11) Calculate the average values of system indices.

3. Reliability Cost Evaluation Considering the Momentary Interruption of Distribution Systems

Several evaluation indices of each sustained and momentary interruption are previously introduced. Although SAIFI and SAIDI, MAIFI, and $MAIFI_E$ are individually worthy tool to evaluate the impact of sustained and momentary interruptions. However, they do not give a complete solution of whole system damages. For example, If the simulation results of SAIDI, SAIFI, MAIFI, and $MAIFI_E$ have same value, then it is difficult to compare the impacts of customers. Therefore, the unification tools for two disturbances are needed.

3.1 Basic Concept and Customer Interruption Costs

In order to reflect the severity or significance of integrated system damages due to the sustained and momentary interruption, the unified reliability evaluation method are proposed. The concept of unified reliability evaluation in distribution system is illustrated in Fig. 2. As shown in Fig. 2, the evaluation element are integrated into the customer interruption cost (CIC) for each sustained and momentary interruption.

One convenient way to display customer interruption costs is in the form of sector customer damage functions (SCDF). The SCDF is the function of interruption duration and cost for each customer type. The basic idea in the SCDF approach is to model the outage cost as a function of interruption duration. Therefore, the interruption cost for any duration can be calculated using the SCDF. The unified reliability cost evaluation is also proposed the analytic and probabilistic methodologies.

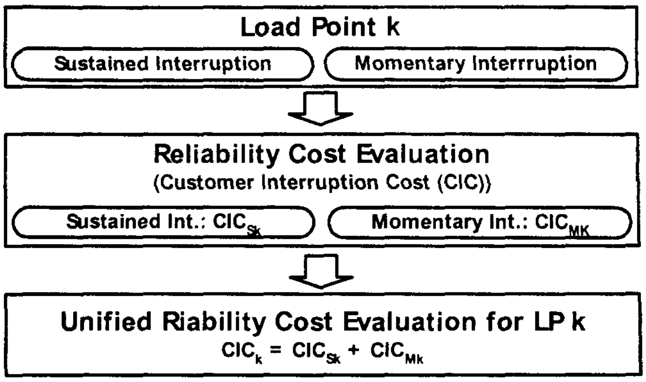


Fig. 2. Unified reliability cost evaluation

3.2 Proposed Analytic Technique of Reliability Cost Evaluation

The basic procedures used in the analytic reliability cost evaluation method can be summarized in the following steps:

Step 1) Finds the average permanent failure rate λ_{Sj}, the average temporary failure rate λ_{Mj}, the average outage time r_j and the average switching time S_j for a failed section j. The line length and protective device type of sample system should be collected

Step 2) Finds the permanent failure rate λ_{Sij}, the temporary failure rate λ_{Mij}, and the permanent outage duration r_{Sij} for a load point i due to a failure section j.

Step 3) Determines the per unit (kW) interruption cost c_{Sij} and c_{Mij} for the sustained and momentary interruptions, respectively. It is calculated as following equations

$$c_{Sij} = f(r_{Sij}), \tag{5}$$

$$c_{Mij} = f\left(\sum_{k=1}^{N_r} \lambda_{Mij} \times P_{r_k} \times t_{r_k}\right), \tag{6}$$

where $f(x)$ is the customer damage function of each customer sector.

Step 4) Evaluates the expected interruption cost of the load point i caused by failure of section j as following equation.

$$ECOST_{ij} = L_i(c_{Sij}\lambda_{Sij} + c_{Mij}\lambda_{Mij}), \tag{7}$$

where L_i is the average load (kW) of load point i.

Step 5) Repeat from *Step 1* to *Step 4* for all sections. The total expected cost of a load point i is

$$ECOST_i = \sum_{j=1}^{N_j} ECOST_{ij} \tag{8}$$

Here, N_j is the total number of sections in the system.

Step 6) Evaluates the total system expected cost ($ECOST$) as following equation.

$$ECOST = \sum_{i=1}^{N_{LP}} ECOST_i \tag{9}$$

3.3 Proposed Monte Carlo Simulation of Reliability Cost Evaluation

The basic procedure used in the probabilistic reliability cost evaluation can be summarized in the following steps:

Step 1) Generate two random numbers for each element in the system and convert these random numbers into TTF (time to failure) and TTTF corresponding the element failure probability distribution.

Step 2) Determine the elements with minimum TTF and TTTF.

Step 3) Generate two random numbers for the element with minimum TTF and convert them into TTR (time to repair) and TTS (time to switch).

Step 4) Generate a random number for the element with minimum TTTF and convert it into reclosing scheme (reclosing success (1^{st}, 2^{nd}, ...) or failure).

Step 5) Find the load points that are affected by the failed sections.

Step 6) Finds the permanent failure rate, the temporary failure rate and the duration of permanent and temporary failure for the load points due to a failure sections.

Step 7) Using the permanent (r_{Sij}) and temporary (t_{Mi}) failure duration, determines the per unit interruption cost c_{Sij} and c_{Mij} for the sustained and momentary interruptions.

Step 8) Evaluate the interruption cost $COST_{ij}$ of the load point i caused by failure of section j as following equation.

$$COST_{ij} = L_i (c_{Sij} + c_{Mij}) \tag{10}$$

Step 9) Generate two random numbers for the repaired section and convert it into a new TTF and TTTF. Return to *Step 2* if the simulation time is less than one year, otherwise, go to *Step 10.*

Step 10) Record the interruption costs of sustained and momentary interruptions for all load points that are affected by the failed sections for a year.

Step 11) If the total simulation time is less than the specified simulation time, go to *Step 12,* otherwise, go to *Step 13.*

Step 12) Generate two new random numbers for the repaired element and convert it into the new TTF and TTTF, and go to *Step 2.*

Step 13) Calculates the total interruption cost of a load point for the simulation years as following equation.

$$COST_i = \sum_{1}^{S} \left(\sum_{j=1}^{N_S} COST_{ij} \right) \tag{11}$$

Here, S is the total number of failure events in the specified simulation period and N_S denotes the total number of sections in system.

Step 14) Calculates the expected interruption cost $ECOST_i$ as following equation.

$$ECOST_i = \frac{COST_i}{TST} \tag{12}$$

where TST is the total specified simulation time in years.

Step 15) Calculates the system $ECOST$ using Eq. (9).

4. Case Study

4.1 Data for Case Study

4.1.1 Test System and Historical Reliability Data

The modified RBTS (Roy Billinton Test System) distribution bus #2 is used for the test system [12]. The modified parts of the original model are shown in [13]. The test system topology is shown in Fig. 3.

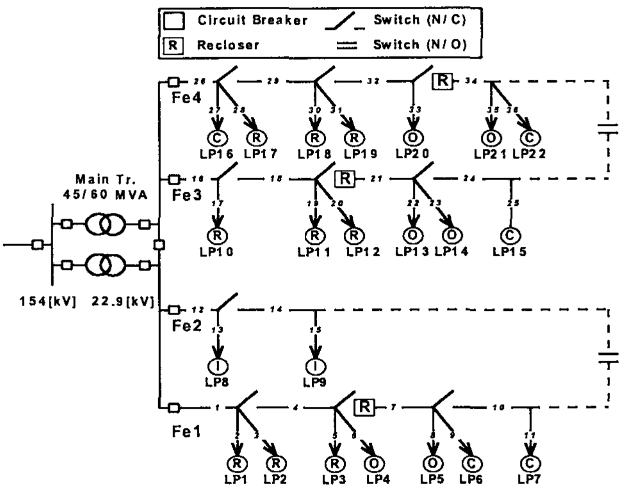


Fig. 3. Configuration of modified RBTS system

Table 1. Reliability data of case studies

Components \ Fault type	Sustained: Failure rate per year	Sustained: Repair time per failure	Momentary: Failure rate per year
Line	0.034 /km	0.5 hour	0.160 /km
Circuit breaker	0.002	3 hour	-
Reclosers	0.002	3 hour	-
Switches(N/C, N/O)	0.002	3 hour	-

Table 2. CIC of case study and customer load level

Customer interruption cost (US$/kW)							
Customer types	Momentary interruption		Sustained interruption				
	0.5sec	15sec	1min	20min	1hr	4hr	8hr
Residential	0.00068	0.0052	0.021	0.093	0.482	4.914	15.69
Commercial	0.02932	0.2198	0.881	2.969	8.552	31.32	83.01
Office	0.15912	1.1923	4.778	9.878	21.06	68.83	119.2
Industrial	0.05412	0.4055	1.625	3.868	9.085	25.16	55.81

Customer load level

Load points	Customer type	Average load (MW)	Number of customers
1-3, 10, 11	Residential	0.535	210
12, 17-19	Residential	0.450	210
8	Industrial	1.00	1
9	Industrial	1.15	1
4-5, 13-14, 20-21	Office	0.566	1
6, 7, 15, 16, 22	Commercial	0.454	12

Table 3. Comparison of SAIFI and SAIDI for each feeders

Feeders	SAIFI (int./yr · cus.)		SAIDI (hr/yr · cus.)	
	Analytical method	Monte Carlo Method	Analytical method	Monte Carlo Method
Feeder1	0.4558	0.4567	0.1295	0.1291
Feeder2	0.3039	0.3050	0.0917	0.0925
Feeder3	0.3886	0.3891	0.1216	0.1217
Feeder4	0.4501	0.4477	0.1282	0.1304

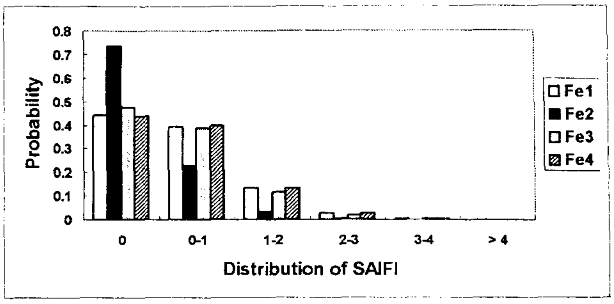
The historical reliability data used in the case studies are shown in Table 1 [14]. The annual distribution system reliability data of KEPCO in the Kyŏng-In district is used.

4.1.2 Data for Calculation of Customer Interruption Costs

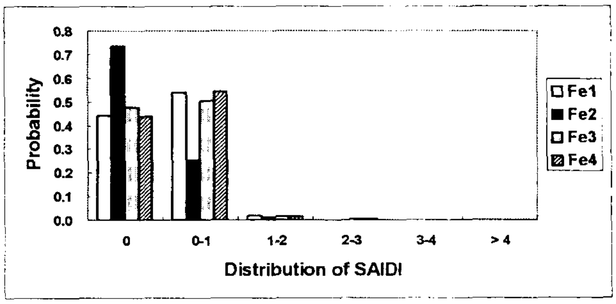
The data related to the customer interruption costs for sustained and momentary interruptions and customer load level are shown in Table 2. The CIC data of Table 2 are calculated from the SCDF survey of Canada. The durations of momentary interruption in Table 2 is shown in 0.5sec and 15sec. It is the reclosing dead-time of protective devices of distribution systems in Korea.

4.2 Results of Case Study

The whole result is simulated by analytic method and Monte Carlo simulation method, respectively. The random number generation function for the conditions of faults frequency and duration and the switching times is selected the exponential function. The total simulation time is determined by 50,000 years.



(a) SAIFI of each feeder



(b) SAIDI of each feeder

Fig. 4. Probability distributions of SAIFI and SAIDI

4.2.1 Results of Sustained Interruptions

The results of sustained interruptions for case studies summarize SAIFI and SAIDI. Table 3 shows the comparison of analytic method and Monte Carlo simulations of SAIFI and SAIDI for each feeder. In feeder 1, 3 and 4, SAIFI and SAIDI are higher than that in the feeder 2 because the line lengths are longer than the feeder 2. Fig. 4 illustrates the probability distributions of SAIFI and SAIDI for all feeders of test system.

4.2.2 Results of Momentary Interruptions

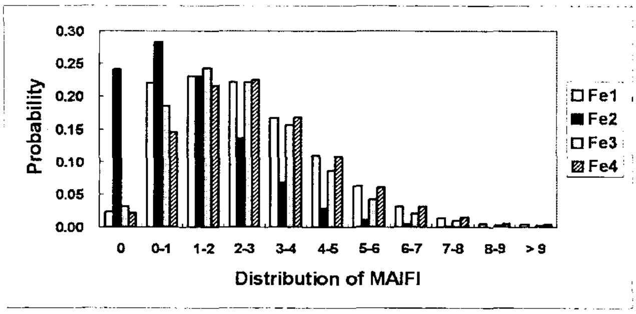
The results of momentary interruptions for case studies summarize MAIFI and $MAIFI_E$. To verifying the validation of simulation, we compare the results of analytical method with the average results of Monte Carlo method. The values of MAIFI and $MAIFI_E$ for all feeders are shown in Table 4. As shown in Table 4, the trend of simulation results for momentary interruptions and momentary interruption events is similar to the sustained interruptions one. The probability distributions of MAIFI and $MAIFI_E$ for each feeder are shown in Fig. 5.

4.2.3 Results of Reliability Cost Evaluation

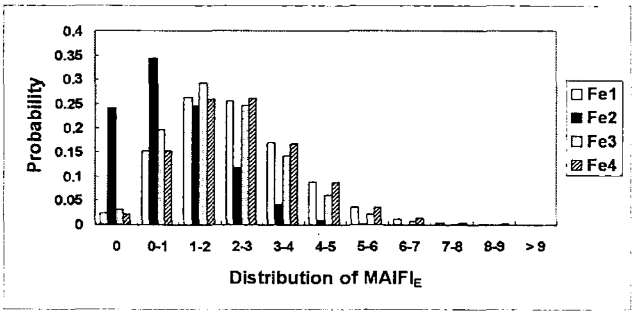
The simulation results of interruption costs for case study are divided into the analytic method and probabilistic results using the time sequential Monte Carlo method. The

Table 4. Comparison of MAIFI and MAIFI$_E$ for each feeders

Feeders	MAIFI (int./yr · cus.)		MAIFI$_E$ (int./yr · cus.)	
	Analytical method	Monte Carlo Method	Analytical method	Monte Carlo Method
Feeder1	2.5079	2.5004	2.1316	2.1275
Feeder2	1.6638	1.6642	1.4160	1.4159
Feeder3	2.1297	2.1345	1.8125	1.8161
Feeder4	2.4697	2.4666	2.1019	2.0986

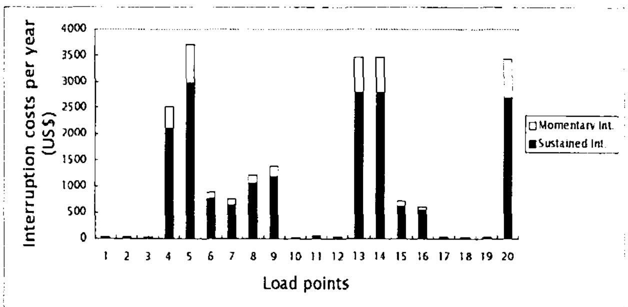


(a) MAIFI of each feeder

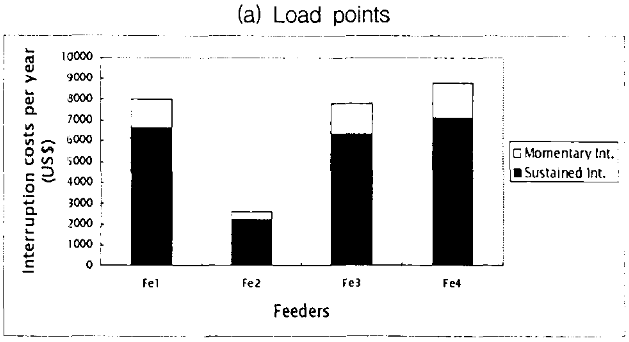


(b) MAIFI$_E$ of each feeder

Fig. 5. Probability distributions of MAIFI and MAIFI$_E$

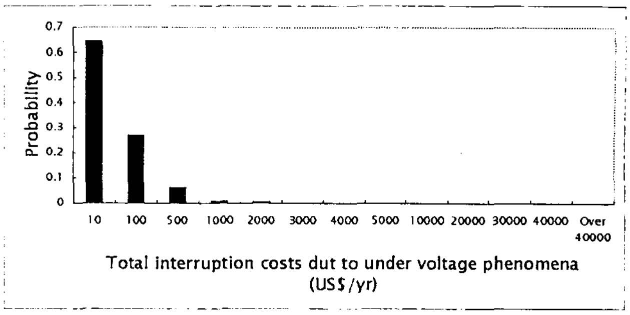


(a) Load points

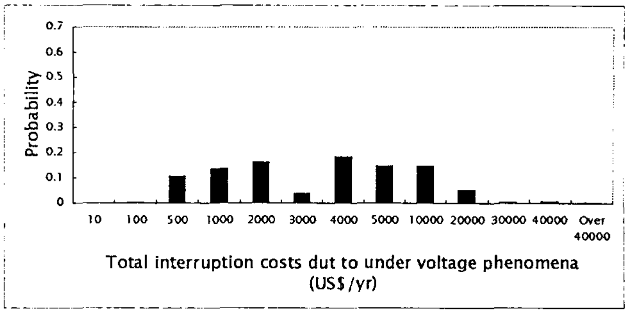


(b) Feeders

Fig. 6. Total average interruption costs



(a) LP1



(b) LP21

Fig. 7. Probability distributions of total CIC (LP1, LP22)

Table 5. Total interruption costs of each load point
(SI: Sustained Interruption, MI: Momentary Interruption)

Load Points	Costs per year (US$)					
	Analytic Method			Monte Carlo Method		
	SI	MI	Total	SI	MI	Total
LP1	42.50	1.62	44.12	41.49	1.61	43.10
LP2	42.50	1.62	44.12	41.49	1.61	43.10
LP3	47.21	1.62	48.83	47.20	1.61	48.81
LP4	2114.24	396.72	2510.96	2112.23	396.69	2508.92
LP5	2982.29	736.24	3718.53	2980.28	733.92	3714.20
LP6	768.67	108.84	877.51	767.67	107.21	874.88
LP7	644.14	108.84	752.98	645.13	107.21	752.34
LP8	1055.50	163.87	1219.37	1053.52	165.95	1219.47
LP9	1191.58	188.46	1380.04	1190.68	187.55	1378.18
LP10	29.87	1.40	31.27	30.77	1.42	32.19
LP11	49.49	1.40	50.89	49.29	1.42	50.71
LP12	41.62	1.17	42.79	40.61	1.17	41.78
LP13	2802.72	665.84	3468.56	2801.38	665.50	3466.88
LP14	2802.72	665.84	3468.56	2801.38	665.50	3466.88
LP15	615.69	98.44	714.13	614.69	99.17	713.88
LP16	549.10	58.68	607.78	549.74	58.73	608.47
LP17	35.60	1.36	36.96	34.10	1.37	35.47
LP18	39.49	1.36	40.85	38.11	1.37	39.48
LP19	39.49	1.36	40.85	38.11	1.37	39.48
LP20	2688.38	736.14	3424.52	2685.12	736.24	3421.36
LP21	2994.11	736.14	3730.25	2991.04	736.24	3727.28
LP22	772.28	108.84	881.12	771.65	108.12	879.77

total average interruption costs of each load point are shown in Fig. 6. The probability distributions of total interruption costs for LP1 and LP21 are shown in Fig. 7.

As shown in Table 5, the average results of proposed analytic and probabilistic method have similar results. It is verify that the two proposed evaluation methodologies of reliability cost are adequately. We can also find that the total interruption cost considering momentary interruptions much differ to the each customer type because the SCDF is much affected for each customer type.

5. Conclusion

In this paper, a novel approach to assess the reliability of distribution system is proposed. The proposed method contains the conventional reliability elements, sustained interruptions in addition to the voltage magnitude quality elements, momentary interruptions. An analytic and probabilistic evaluation method for momentary interruptions is proposed. The time sequential Monte Carlo method is introduced for the probabilistic evaluation approach. The unified method of reliability evaluation using the interruption cost is proposed. The proposed unified method of reliability evaluation is also divided into the analytic and probabilistic techniques. Through the case study, the actual application of proposed unified methods using analytic technique and Monte Carlo simulation is verified. The proposed evaluation method could be used to evaluate the impact of voltage quality phenomena on customers from the viewpoints of entire distribution system.

References

[1] R. Billinton and R. N. Allan, Reliability evaluation of power systems (second edition), New York: Plenum Press, 1996.

[2] R. Billinton and W. Li, Reliability assessment of electric power systems using Monte Carlo methods, New York: Plenum Press, 1994.

[3] R. Billinton and R. N. Allan, Reliability evaluation of engineering systems- concepts and techniques, New York: Plenum Press, 1983.

[4] R. Billinton and P. Wang, "Distribution system reliability cost/worth analysis using analytical and sequential simulation techniques," IEEE Trans. on PWRS, vol. 13, no. 4, pp. 1245-1250, Nov. 1998.

[5] IEEE trial-use guide for electric power distribution reliability indices, IEEE Std. 1366, 1998.

[6] C. M. Warren, "The effect of reducing momentary outages on distribution reliability indices," IEEE Trans. on PWRD, vol. 7, no. 3, pp. 1610-1617, Jul. 1992.

[7] R. E. Brown, S. Gupta, R. D. Charistie, S. S. Venkata, and R. Fletcher, "Distribution system reliability assessment: momentary interruptions and storms," IEEE Trans. on PWRD, vol. 12, no. 4, pp. 1569-1575, Oct. 1997.

[8] R. E. Brown and J. R. Ochoa, "Distribution system reliability: default data and model validation," IEEE Trans. on PWRS, vol. 13, no. 2, pp. 704-709, May 1998.

[9] R. C. Dugan, M. F. McGranaghan, and H. W. Beaty, Electrical power systems quality, New York: McGraw-Hill, 1996.

[10]J.-C. Bae, J.-C. Kim, S.-Y. Yun, "Reliability assessment considering the momentary voltage quality in power distribution systems," KIEE Int. Trans. on PE, vol. 12A, no. 2, pp. 57-65, June 2002.

[11]Math H. J. Bollen, Understanding power quality problems- voltage sags and interruptions, New York: IEEE Press, 2000.

[12]R. N. Allan, R. Billinton, I. Sjarief, L. Goel, and K. S. So, "A reliability test system for educational purposes- basic distribution system data and results," IEEE Trans. on PWRS, vol. 6, no. 2, pp. 813-820, May 1991.

[13]S.-Y. Yun, J.-H. Oh, O.-S. Kim, N.-K. Kim, and J.-C. Kim, "An enhanced method for assessing the effect of voltage sag in power distribution system using a fuzzy model," Trans. on KIEE, vol. 49A, no. 4, pp. 177-184, Apr. 2000.

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