Making Decision of the Maintenance Priority of Power Distribution System using Time Varying Failure Rate and Interruption Cost

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Abstract – The purpose of the this paper is to make decision of the maintenance priority of power distribution system using Time-Varying Failure Rate(TVFR) with interruption cost. This paper emphasizes the practical use of the reliability indices and interruption cost. To make a decision of maintenance priority on power distribution system equipment, the quantification of the reliability level should be represented as a cost. In this paper, the TVFR of power distribution system equipment applied in this paper utilizes analytic method to use the historical data of KEPCO. From this result, the sensitivity analysis on TVFR of equipment was done for the priority, which represents that high priority of the equipment has more effect on system reliability, such as SAIDI or SAIFI, than other equipment. By this priority, the investment plan is established. In this result, customer interruption cost(CIC) could be extracted, and CIC is used as weighting factor to consider a importance of customer. After that, the result calculated the proposal method in this paper is compared with other priority method, such as lifetime, failure rate or only sensitivity.

Keywords: Reliability, Sensitivity analysis, Investment plan, Interruption cost, Weighting factor

1. Introduction

Recently, the power distribution system is asked to supply the electric service of high quality and reliability to customer. For these needs, utility has focused on the reliability and power quality of customer. In the past, a issue of reliability was always based on high reliability without economy and the investment method is excluded in bulk. However, it is not possible to consider the issue of reliability without economy, because high reliability goes with high investment cost. Therefore, the improvement reliability imposes the high investment cost on the customer.

The current investment of power distribution system equipment in Korea Electric Power Corporation (KEPCO) is planned to minimize the interruption time per customer and the power loss. For this minimization, utility has to decide the investment priority of the system equipment. However, this decision method is hard to quantify which investment priority has a more effective and how the priority is made as cost to compare with interruption cost. In addition, to extract the accurate influence of equipment's failure rate and to reflect the influence is more difficult than the difficulty mentioned above.

There are various papers about the reliability analysis.

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The mainstream of reliability study is to extract the interruption cost and the failure rate [1-4]. However, these studies only proposed the way of calculation on system reliability and failure rate. There are no practical uses of reliability. The other paper proposed the practical use of reliability [5,6]. However, these papers did not consider an economical effect by the failure of system equipment. The sensitivity analysis was done for making priority decision. In the case that the sensitivity analysis is only used when the priority is extracted, the important level of customer could not be considered. It means that there is no way to select which equipment has high priority position if more than two facilities have the same result on the sensitivity analysis.

In this paper, the method that makes decision of maintenance priority on power distribution system's equipment using TVFR and CIC is proposed. To use the TVFR and system reliability such as SAIDI (System Average Interruption Duration Index) or SAIFI (System Average Interruption Frequency Index), the sensitivity analysis is done. It means how much the change of the system equipment' failure rate has an influence to the system reliability. The investment of equipment following the produced priority by the result of the sensitivity analysis can make CIC less than before investment, and the CIC of the equipment could be extracted. After that, we could make the weighting factor by total CIC of system and the CIC, made by changing equipment. This factor means which component is connected with important customer. Finally, the result of sensitivity analysis considering weighting factor is extracted. To verify that the result is more economical effect than other priority, the result by proposed method was compared with the other priority by other method.

2. Investment Priority Decision Flow of Proposed Method

2.1 Proposed Method for Priority

For the priority of investment plan, the sensitivity analysis and the extraction of weight is necessary. First of all, to analyze the sensitivity on system reliability depending on the change of the system equipment' failure rate, the extraction of basic reliability indices is necessary, such as a lifetime, restoration time(r), Unavailability(U) and failure rate(Λ). In this extraction, the lifetime of equipment is for cutting down a number of a calculation. If the sensitivity analysis of many facilities of power distribution systems is done, calculating time is too long, and so to compare equipment lifetime with the operation time is necessary. Next step is to carry out the sensitivity analysis. The sensitivity analysis is defined as the influence of the equipment's failure rate for system reliability. This is a measure of how much the final value of the system reliability results will be changed by only changing the one equipment's failure rate with fixing others. Therefore, the sensitivity analysis on reliability is which equipment has large effect on system reliability in case the other equipments' failure rates are fixed.

Firstly, the system reliability indices as SAIDI and SAIFI are expressed as following equations, and the sensitivity equation is eq.(3).

$$SAIDI_s = \frac{\sum_{j=1}^{m}\left(\left(\sum_{i=1}^{n} U_i - \sum_{i=1}^{n} U_i'\right) \times N_j\right)}{\sum_{j=1}^{m} N_j} \quad (1)$$

$$SAIFI_s = \frac{\sum_{j=1}^{m}\left(\left(\sum_{i=1}^{n} \lambda_i - \sum_{i=1}^{n} \lambda_i'\right) \times N_j\right)}{\sum_{j=1}^{m} N_j} \quad (2)$$

n, m : the number of equipment and load point respectively.
U_i, λ_i : Sum of the unavailable time and failure rate on load point j respectively.
U_i',λ_i' : Sum of the unavailable time and failure rate to change the failure rate of i-th equipment connected to load point j respectively.
N_j : The number of customer in load point j.

$$\alpha_k = \frac{SRI_{j-1,k} - SRI_{j,k}}{\lambda_{j-1,k} - \lambda_{j,k}} \quad (3)$$

SRI is the system reliability index, the λ is failure rate. The

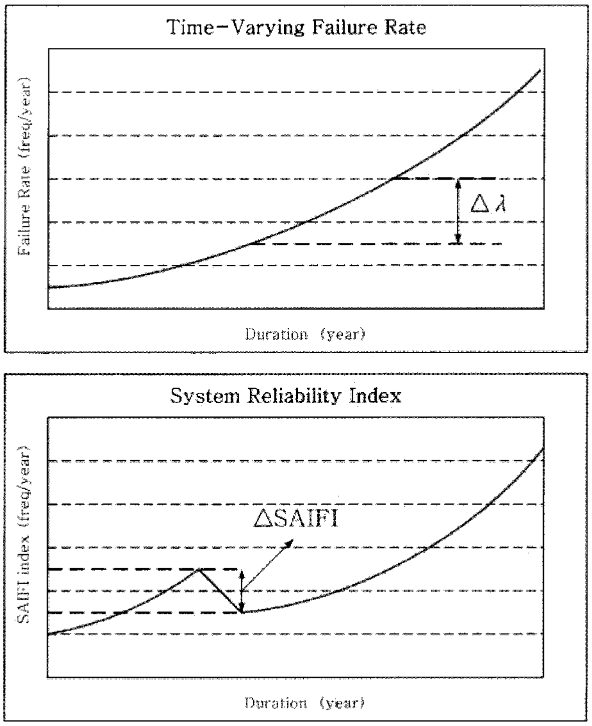

Fig. 1. Concept of the Sensitivity

j is the operation time. It means how much the system reliability index (SRI) is changed when the failure rate of the equipment k operating for j years is gone down as like the failure rate in j-1 years to change or repair the equipment k.

However, it is not enough to decide priority of facility on distribution system. Even though the equipment which is selected first priority is invested, there is no way to consider the system configuration on which equipment is connected with customer. To reflect this concept, the indices such as the customer type and load demand would be considered, and so the interruption cost is most pertinent to the concept. Therefore, sensitivity equation, which can consider effect of interruption cost, is necessary. Following equation is the priority equation suggested in this paper.

$$P_k = \alpha_k \times WF_k \quad (4)$$

In eq(4), Pk is the priority of equipment k. the WF_k is a weight of equipment k. The WF_k is effect of interruption cost by failure event of equipment k. In other words, this factor presents how much the interruption cost by equipment k has an effect on the system interruption cost. Equation on weighting factor is as following below.

$$WF_k = \frac{Interruption\ Cost_k}{Total\ Interruption\ Cost\ of\ System} = \frac{\sum_{l=1}^{m} C_{sc(l)} \times L_l \times \lambda_k}{\sum_{l=1}^{m}\sum_{k=1}^{n} C_{sc} \times L_l \times \lambda_k} \quad (5)$$

The $C_{sc(l)}$ is composited customer interruption cost in load point l, and L_l is load demand of load point l, λ_k is failure rate of facility k. The m and n are total number of load point and equipment in estimated model respectively.

After that, new sensitivity level extracted by the proposed method is arrayed from high to low, and the investment cost is calculated depending on the priority determined by the array. This flow is showed as Fig. 2.

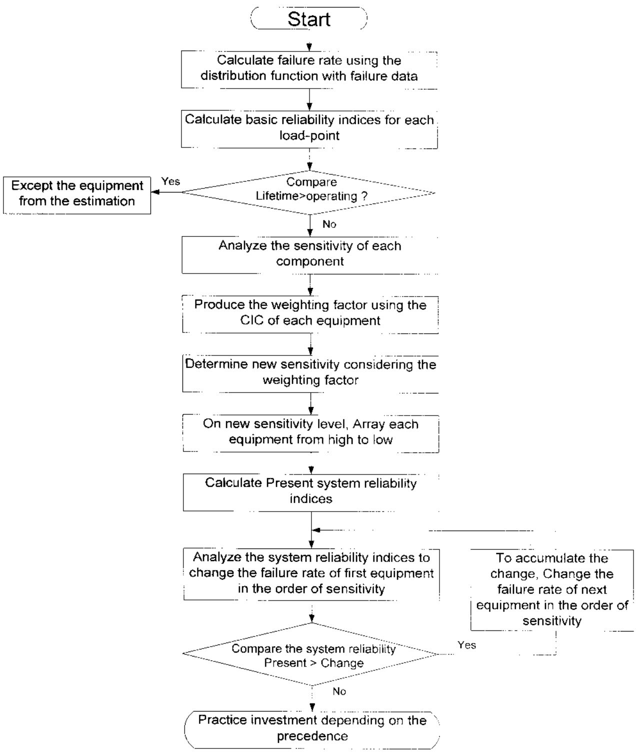

Fig. 2. Algorithm suggested in this paper

2.2 Time-Varying Failure Rate(TVER)

function. The failure rate is defined as a frequency of equipment's fault occurred by effect of environment, any incidents or deterioration between optional time and time when the breakdown occurs. These kinds of faults are different character, so the distribution function is differently used as corresponding with character of fault mode. The TVFR is classified into two classes, depending on fault types as a random failure, occurred by natural phenomena and accident in regardless of equipment lifetime, and an aging failure occurred by out of lifetime due to deterioration, wearing and corrosion.

In two kinds of failure type, TVFR is calculated by following an expression [7].

$$\lambda(t) = \lambda_R + \lambda_A(t) \tag{6}$$

$\lambda(t)$ is TFR. $\lambda_R(t)$ and $\lambda_A(t)$ are the random failure rate and the aging failure rate respectively. In this paper, the TVFR considering maintenance effect is used [8].

2.3 Sector Customer Damage Function(SCDF)

To extract the weight on the system equipment, the Sector Customer Damage Function (SCDF) is necessary. This data of SCDF studied in [10] is used as Fig (3).

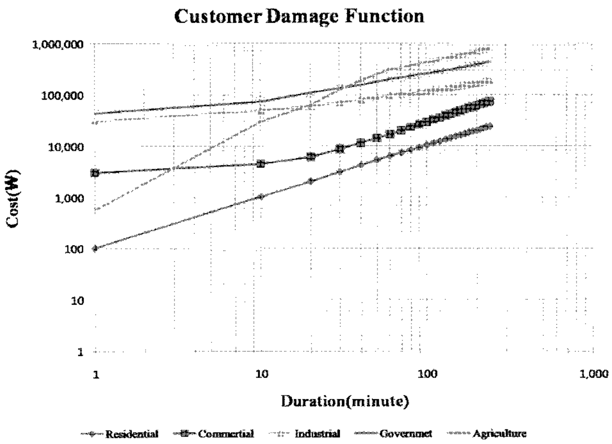

Fig. 3. Customer damage functions for different sectors

3. Case Study and Result

For verifying the proposed method, the case study and other method comparing with this proposed method are necessary.

3.1 Case Study

In order to extract the priority by the proposed method and others, the distribution system model is used as shown in Fig. 5, which is titled RBTS bus 2-model. In this model, the average values of customer loads are used, and the types of customer classified into 4 classes such as residential, small user, commercial and government are used. The feeders are operated as radial feeders, but connected as a mash through normally open sectionalizing point. The failure rate of the system equipment considering maintenance effect is used as mentioned above, as like Fig.5. The other data related to this model are shown in Table 1-3.

Table 1. Feeder Type and Lengths

Feeder Type	Length [km]	Feeder Section Numbers
1	0.60	2,6,10,14,17,21,25,28,30,34
2	0.75	1,4,7,9,12,16,19,22,24,27,29,32,35
3	0.8	3,5,8,11,13,15,18,20,23,26,31,33,36

Table 2. Customer Data

Number	Load Point	Customer Type	Average Load level [MW]	Number of Customers
5	1-3,10,11	Residential	0.535	210
4	12,17-19	Residential	0.450	200
1	8	Small User	1.00	1
1	9	Small User	1.15	1
6	4,5,13,14,20,21	Govt/Inst	0.566	1
5	6,7,15,16,22	Commercial	0.454	10
Total			12.291	1,908

Table 3. Repair time and Construction cost of each facility

	Repair time (minute)	Switch Time (minute)	Cost
Overhead line	30	3	38,934,000 (₩/km)
Transformer	200		4,046,000 (₩/unit)

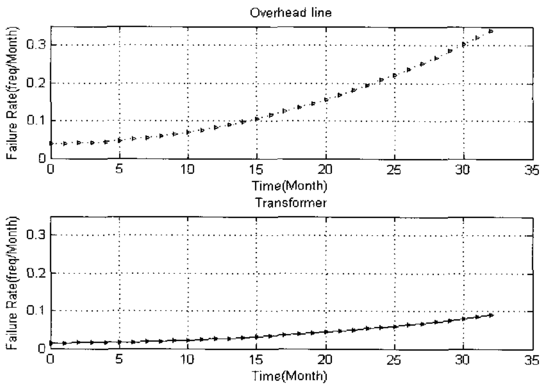

Fig. 4. The failure rate used in study case

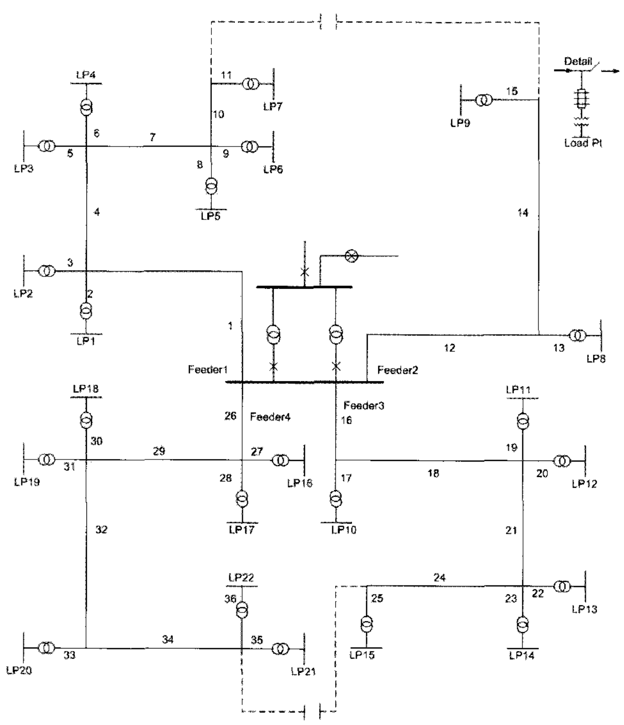

Fig. 5. Sample distribution systems model

Table 4. Change of reliability indices for 10-years

Year	Feeder1		Feeder2	
	SAIFI	SAIDI	SAIFI	SAIDI
1	0.233897	15.018404	0.102512	2.206392
2	0.249387	15.942048	0.109530	2.357434
3	0.267085	16.923737	0.117786	2.535130
4	0.286991	17.963471	0.127280	2.739480
5	0.309107	19.061251	0.138013	2.970485
6	0.333431	20.217076	0.149984	3.228144
7	0.359964	21.430946	0.163194	3.512458
8	0.388705	22.702862	0.177642	3.823426
9	0.419656	24.032823	0.193328	4.161048
10	0.452814	25.420829	0.210253	4.525325
11	0.485094	27.046571	0.226195	4.867824
12	0.522404	28.678859	0.245231	5.277471
13	0.562585	30.409657	0.265868	5.721591
14	0.605856	32.244911	0.288242	6.203086
15	0.652455	34.190924	0.312498	6.725101
Year	**Feeder3**		**Feeder4**	
	SAIFI	SAIDI	SAIFI	SAIDI
1	0.235288	15.039880	0.233229	14.955274
2	0.250873	15.964994	0.248673	15.874596
3	0.268683	16.948412	0.266317	16.851200
4	0.288719	17.990136	0.286162	17.885088
5	0.310980	19.090164	0.308208	18.976258
6	0.335466	20.248497	0.332454	20.124710
7	0.362179	21.465134	0.358900	21.330446
8	0.391116	22.740077	0.387548	22.593464
9	0.422279	24.073324	0.418396	23.913764
10	0.455668	25.464876	0.451444	25.291348
11	0.488031	27.082770	0.483206	26.964842
12	0.525567	28.717243	0.520320	28.597916
13	0.565991	30.450358	0.560284	30.329895
14	0.609524	32.288068	0.603317	32.166768
15	0.656405	34.236686	0.649656	34.114887

Table 4 is the system reliability values calculated using the equipments' TVFR.

3.2 Result of Case Study

The strategies of maintenance and investment for managing stable system reliability are certainly necessary. These strategies have different efficiency by the method how much investment cost is used and which investment method is used for ordering facilities on management of system reliability. There are typical methods to establish a plan such as an estimation of facilities' service time, meaning duration of operation compared with lifetime, and failure rate, meaning which component's failure rate is higher than others.

To illustrate efficiency of the method suggested in this paper, reliability indices (SAIFI and SAIDI) and interruption cost are respectively estimated by typical method with the suggested method for the sample model.

The sensitivity of reliability on facility is different by priority decision method, so that result of reliability is different by each investment method estimating the sensitivity. Also, limited construction cost on investment has different effect. If facilities which are low construction cost are selected in high order after being estimated sensitivity by any method, much work could be done in limited construction cost, so reliability level should be higher than others.

Table 5. The change of reliability indices by investment methods with rate of investment cost

Index		SAIFI	SAIDI	Interruption cost
N-sensitivity				
Rate of Investment	10%	0.250727	16.16268	199,943,176
	30%	0.205905	9.091473	105,516,754
	50%	0.185523	5.035394	82,339,845
	70%	0.170973	4.787462	77,424,750
	90%	0.162091	4.574471	56,359,987
T-sensitivity				
Rate of Investment	10%	0.259001	16.18095	218,641,552
	30%	0.226823	10.10623	131,202,785
	50%	0.22588	5.875057	81,750,957
	70%	0.174362	4.613612	79,021,968
	90%	0.162326	4.51725	57,012,073
Failure rate				
Rate of Investment	10%	0.25092	16.19855	196,770,950
	30%	0.213346	15.9114	144,122,511
	50%	0.194453	15.72744	126,879,946
	70%	0.179537	4.744243	88,724,033
	90%	0.162995	4.580125	56,361,204
Lifetime				
Rate of Investment	10%	0.2514	16.15851	217,090,982
	30%	0.2384	15.982	175,552,011
	50%	0.223568	12.53737	114,282,509
	70%	0.201796	8.856774	95,086,866
	90%	0.189556	8.498135	51,127,035

Next figures illustrate the trend of reliability result by investment plan limited construction cost as 10%, 30%, 50%, 70% and 90% of total construction cost.

In the figures below show, the results of T-SAIFI and T-SAIDI are produced by only sensitivity estimation, and the N-SAIDI and N-SAIFI are produced by suggested sensitivity estimation.

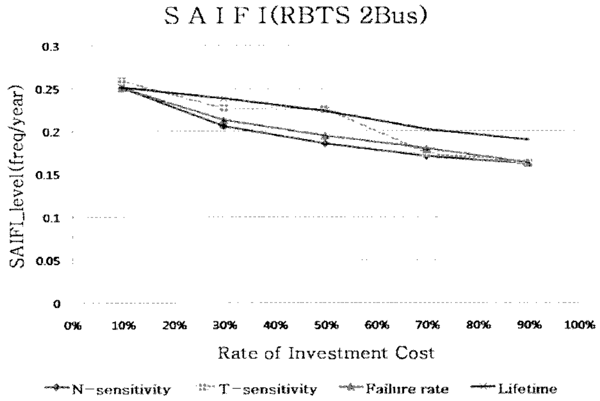

Fig. 6. Result of case study (change of SAIFI)

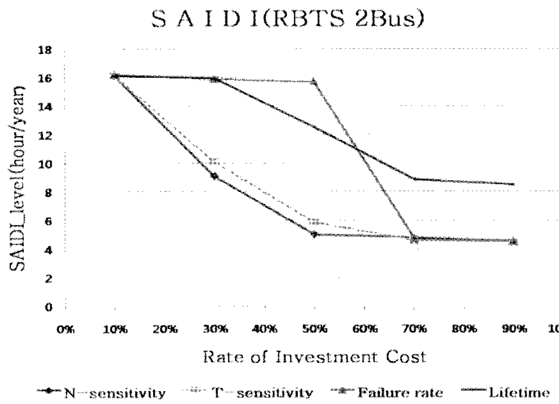

Fig. 7. Result of case study (change of SAIDI)

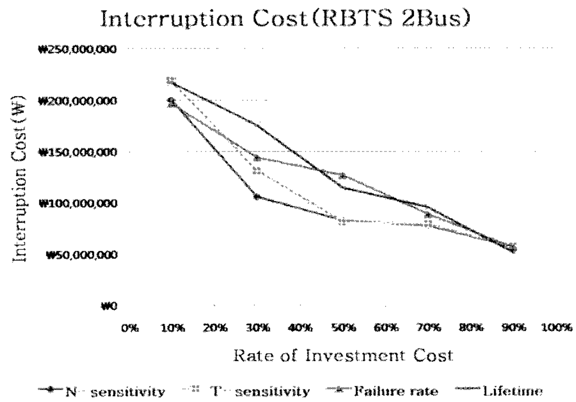

Fig. 8. Result of case study (change of Interruption Cost)

In each case, the results of study case in Fig.6-8 presented that the effect of a priority by lifetime is worst economic effect, and the effect of a priority extracted by the proposed method is best economic effect among the comparison.

The effect of the priority by traditional sensitivity is nearly same with the effect of the proposed method. It is due to change the investment priority slightly. It means that the importance of customer is little, so to do the sensitivity analysis without the weight is enough in this model.

4. Conclusion

In this paper, we proposed the extraction method of the investment priority using the TVFR applied for extracting the equipment priority to use the sensitivity analysis of the equipment's TVFR on system reliability. Also, interruption cost is used for extract the weight of the equipment to consider the customer. It is necessary to consider a economic effect of the equipment.

For focusing the economical efficiency, two kinds of cost, such as interruption cost, for using as the weight to consider customer and system configuration, and investment cost, extracted by the sensitivity analysis, is necessary for the estimation. This paper suggests the method to extract the priority of investment cost considering interruption cost and TVFR. First, the sensitivity analysis on equipment's TVFR is done for calculating which equipment has more improvement effect on system reliability. Also, the weight of equipment for considering customer and system configuration is extracted to calculate the CIC by equipment's failure with total CIC of system.

In the current electricity market, the proposed method is certainly necessary, because the economic effect should be considered in establishing the investment plan. The proposed method is easy to extract the priority, and the side of customer could be considered at the same time as establishing the investment plan and management plan of power distribution system on side of utility.

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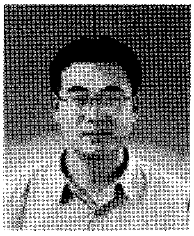

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