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A Study on the Optimal Distribution Loss Management Using Loss Factor in Power Distribution Systems

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분산형전원이 도입된 배전계통의 손실산정기법에 관한 연구

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Abstract Recently, the needs and concerns for the power loss are increasing according to the energy conservation at the level of the national policies and power utilities's business strategies. Especially, the issue of the power loss is the main factor for the determining the electric pricing rates in the circumstances of the deregulation of electrical industry. However, because of the lacking of management for power loss load factors (LLF) it is difficult to make a calculation for the power loss and to make a decision for the electric rates. And loss factor (k-factor) in korea, which is a most important factor for calculation of the distribution power loss, has been used as a fixed value of 0.32 since the fiscal year 1973. Therefore, this study presents the statistical calculation methods of the loss factors classified by load types and seasons by using the practical data of 65 primary feeders which are selected by proper procedures. Based on the above the algorithms and methods, the optimal method of the distribution loss management classified by facilities such as primary feeders, distribution transformers and secondary feeders is presented. The simulation results show the effectiveness and usefulness of the proposed methods.

요 약 본 연구에서는 분산형전원이 연계된 배전계통에서 배전 손실을 설비별로 산정하는 알고리즘과 통계적인 방법에 의하여 배전손실 계수를 산정하는 알고리즘을 제시하여 배전 손실 관리의 정확도를 제고하는 방안을 마련하고자 한다. 먼저, 배전손실에 대한 개념을 정의하고 배전손실 산정시의 문제점에 대하여 분석하고, 배전손실 산정에서 가장 중요한 자료 추출 방법과 대상자료의 유효성 검증하는 방법을 제시한다. 그리고 통계적인 방법에 의한 부하특성계수를 산정하는 알고리즘을 제시하고, 배전손실 요소들간의 상호관계를 규명하며, 배전 설비별(고압배전선로, 배전용변압기, 저압배전선로) 손실계산 알고리즘을 개발한다.

Key Words : Distribution loss, Load factor, Loss load factor, Loss factor

1. Introduction

Recently, the issue of power loss is the main factor for the determining the electric pricing rates in the circumstances of the deregulation of electrical industry. That is to say, the loss correction dependent on the location of installed facility plays an important role in the power price that is fixed at 5 minutes period. Because the loss load factor and the compensation formula during the loss correction are decided through the common agreement of power producers, and consumers, it is not easy to lead to the agreement if exact and reliable basis data is not presented.

The loss of distribution system means the power consumed by electrical characteristics of equipments (in proportion to resister and the square of current), while the power is supplied through primary feeders, distribution transformers, secondary feeders and service lines, from distribution substation to consumers. The total loss can be calculated easily, if it subtracts selling amount from supplying amount. But, it is difficult to make calculation of the loss amount produced by each equipment, because it needs to calculate the loss load factor considering the load

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types, the loss factor and line constants etc.. However, the values now in use are calculated by load characteristics and equipments in 1960s. Especially, it needs to recalculate with change of the operation conditions such as the power factor, step-up of voltage and new-developed equipments. Also, the Korea Electric Power Corporation (KEPCO) has been conducting loss management by sections for primary feeders, distribution transformers, secondary feeders, service lines and electric meters etc., but it is only possible to calculate micro and local loss for the utilization of off-line system information [1-4].

Based on the above, this study proposes the calculation algorithms for the distribution loss by load types and the loss load factor using the statistical methods. To be specific, chapter 2 explains the concepts for distribution loss, and the problems during the loss calculation. Chapter 3 shows the effectiveness of model feeder which is a most important factor in calculation for the distribution loss. And, chapter 4 presents the calculation algorithms for the loss factor using the statistical methods and examines the interrelations of factors for the distribution loss. Chapter 5 is the calculation algorithms for power loss by equipment such as primary feeders, distribution transformers, secondary feeders, and estimates the elements affecting the distribution loss by parameter analysis. Finally, chapter 6 shows the loss amount by equipments with actual system and identifies the effectiveness of the proposed algorithms.

2. Distribution Loss

2.1 Definition of Distribution Loss

The power loss occurs while the power is supplied from distribution substation to last customers, and the distribution loss is expressed in kwh. And the distribution loss is the difference of the power amount used in consumers and sent in distribution substation during a fixed period.

For example, if the power is supplied from upper voltage level, and is sold to consumer of voltage level like a 220/380V distribution system, the supplying energy is determined by Eq. (1).

$$E_{input} = E_{sales} + E_{losses} \tag{1}$$

2.2 Loss Load Factor

In calculating the distribution loss occurred for a fixed period, it is very difficult and inefficient to calculate the distribution loss for all time intervals. Therefore, it is general to calculate distribution loss with the loss load factor that have same concept with the load factor. The loss load factor is the ratio of the average loss and the maximum loss for a fixed period. Namely, if the distribution loss under peak time is calculated, the average loss of relevant period is calculated through the loss load factor and the whole loss amount can be decided by multiplying the average loss.

2.2.1 Load Factor (LF)

As stated above, the load factor of system is defined as a ratio of the average load, and the peak load, for a specific period (1 year).

$$LF = \frac{P_{ave}}{P_{max}} \tag{2}$$

2.2.2 Loss Load Factor (LLF)

The loss load factor is the ratio of the average loss and the peak loss for a fixed period and can be formulated as

$$LLF = \frac{L_{ave}}{L_{max}} \tag{3}$$

Usually, the loss load factor can be calculated with the load factor as

$$LLF = k \times (LF) + (1-k)(LF)^2 \tag{4}$$

Where, constant k is called the loss factor, and is decided with measurement of actual load data and statical analysis. This value has various characteristics by seasons, load types.

2.3 Calculation of the Distribution Loss

Generally, the distribution loss(Loss) can be calculated by

$$LOSS = LLF \times I_m^2 \times R \times T \tag{5}$$

where, L : distribution loss amount (wh), I_m : peak current, R : resister, T : time interval

As the above equation, the loss factor which is the most important factor in calculation for the distribution loss, is required to calculate annually. But,

Table 1. Selection of sample feeder

	Whole Number	Number of Sample Feeder	Number of Model Feeder	Use Target
Whole Feeder	6,631	17.24	65	Loss factor
4 Load Groups	1,658	4.31(18)	5(26)	Annual loss Amount

KEPCO has been used as same value of 0.32 since the fiscal year 1973. Accordingly, the exact calculation for the loss factor by load types and seasons considering load increase, various loads and changes of equipment, is required.

3. Modeling Feeder for Distribution Loss Calculation

Because KEPCO has 6,631 primary feeders that total line length is more than 1.64×10^8m, distribution transformers over 1.5 million, secondary feeders that total line length is more than 1.88×10^8m and service lines etc. according to the record on November, 2003, it is difficult to calculate the distribution loss by equipments exactly. Also, because the load amount and utilization factor by time intervals of each equipment must be required to calculate annual distribution loss, it is almost impossible to calculate the distribution loss of all equipments one by one.

Therefore, statistical methods that convert the distribution loss for sample value to the whole value, are required to calculate annual distribution loss of system. The reasonable selection of distribution feeders is important before everything else since the calculation of representative sample value is kernel in this method. In this study, the number of model feeders is selected with getting valid sample statistically and efficiency of selected model feeders is verified through parameter analysis.

Sampling the model feeders represents the result by selecting branch and regional office including big cities, small towns, farming and fishing villages in KEPCO. This study uses Eq. (6) to decide the number of the minimum sample feeders showing characteristics of groups.

$$N = P \times \frac{1}{4} \times \left(\frac{Z_a}{d}\right)^2 \qquad (6)$$

where, N : number of samples by groups, P : total number of distribution feeders by groups, Z_a : presumption error for sample production, d : constant value corresponded to trust extent

To calculate the number of samples, d is 1.96 equivalent to trust extent 95%, and Z_a, the presumption error is 20%. On this, table 1 shows the number of the minimum sample feeders, one is the value by load characteristics (P=1,658) and the other is relative to the whole feeders (P=6,631).

In this study, the number of model feeders is decided more than sample feeders calculated statistically as shown in Table 1. First, 65 distribution feeders are selected to calculate the loss factor, and finally, each 5 distribution feeders by load characteristics, total 26 distribution feeders are chosen to calculate the annual loss amount.

4. Analysis Algorithm for the Loss Factor

As previously defined, because the loss load factor is the ratio of the average loss (L_{ave}) and the maximum loss (L_{max}) and they are related in square of the maximum current and the average current, the loss load factor is calculated as

$$LLF = \frac{L_{ave}}{L_{max}} = \frac{\sum I_{ave}^2}{I_{max}^2} \qquad (7)$$

$$L_{ave} = I_{ave}^2 \times R \qquad (8)$$

$$L_{max} = I_{max}^2 \times R \qquad (9)$$

Where, I_{ave} and I_{max} mean the average current and the maximum current. The average loss of Eq. (8) is expressed by relation between the average current and resistance, and the maximum loss dependent on the maximum current is calculated from Eq. (9).

If the loss load factor is calculated by above method, the loss factor k can be calculated by relation among the load factor, the loss load factor, and

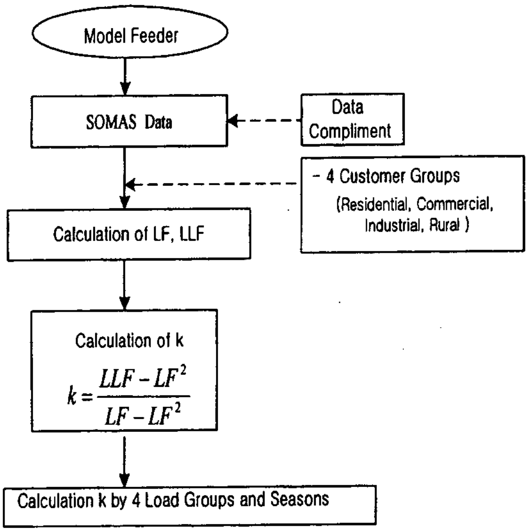


Fig. 1. Calculation algorithm for the loss factor

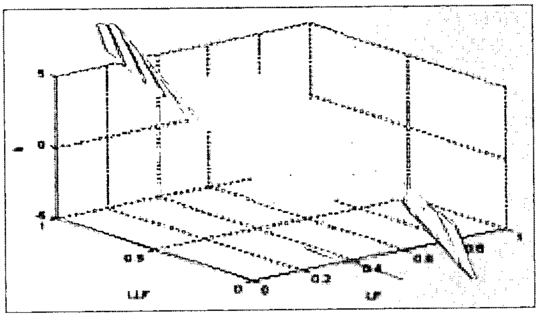


Fig. 2. Relation of loss factor, load factor and loss load factor

the loss factor as

$$k=\frac{LLF-LF^2}{LF-LF^2} \tag{10}$$

The algorithm to calculate the loss factor with the load factor and the loss load factor calculated from SOMAS data is shown in Fig. 1. SOMAS means KEPCO's data base for distribution equipments.

To understand characteristic for the loss factor, the interrelations between the load factor, the loss load factor and the loss factor are shown in Fig. 2 by third dimension graph. If the loss load factor is constant, the increase of the load factor brings the decrease of the loss factor. That is, the loss factor changed according to the load factor has big and small value. And if the load factor is constant, the change of the loss load factor in the case of steep slope, brings a big change of the loss factor. In contrary, the change of the loss load factor in the case of gentle slope, brings a small change of the loss factor. Hence the change of the loss factor depends on the change of the loss load factor and the load factor.

5. Calculation Algorithm for the Distribution Loss

To calculate the exact distribution loss amount, this study presents the calculation algorithm for the distribution loss by equipments such as primary feeders, distribution transformers, secondary feeders etc. To calculate the loss of primary feeders, feeder configuration diagram and load distribution diagram are made from single line diagram of model feeder and SOMAS data. Using the ratios of total energy consumption and the energy consumptions of each customer group, loss ratios among 4 customer groups are derived and the loss of primary feeders for 4 customer groups is calculated. For loss calculation of distribution transformers, using the ratios of the total number of distribution transformer and the number of transformer for each rated capacity group and type, the loss of the distribution transformers for 4 customer groups is calculated with the same algorithm of the primary feeders loss calculation. For loss calculation of secondary feeders, using the composition ratios of line length and line type, the loss of the secondary feeders for 4 customer groups is calculated with the same algorithm of the primary feeders loss calculation.

5.1 Loss Calculation of Primary feeders under Peak Load

① The loss of the primary feeders for 4 customer groups is calculated by the equal load distribution with peak load and the single line diagram.

- Residential loss = total residential loss/9 = A-1(kw)
- Commercial loss = total commercial loss/5 = A-2(kw)
- Industrial loss = total industrial loss/7 = A-3(kw)
- Rural loss = total rural loss/5 = A-4(kw)

② The ratios of total selling power and selling power of each customer group are calculated as

- Residential ratio = residential annual selling power amount/total selling power amount × 100% = B-1 (%)
- Commercial ratio = commercial annual selling power amount/total selling power amount × 100% = B-2 (%)
- Industrial ratio = industrial annual selling power amount/total selling power amount × 100% = B-3 (%)
- Rural ratio = rural annual selling power amount/ total selling power amount × 100% = B-4 (%)

③ The loss of the primary feeders for 4 customer groups is calculated as

- Residential loss = A-1 × B-1 = C-1 (kw)
- Commercial loss = A-2 × B-2 = C-2 (kw)
- Industrial loss = A-3 × B-3 = C-3 (kw)
- Rural loss = A-4 × B-4 = C-4 (kw)
- Others loss = midnight + educational + etc. = C-5 (kw)

④ The total loss of the primary feeders under peak load is calculated as

- Lptotal = C-1 + C-2 + C-3 + C-4 + C-5

5.2 Loss Calculation of Distribution Transformers

① Each iron and copper losses are calculated by using the ratios of the total number of distribution transformer and the number of transformer for each rated capacity group and type.

- 8 rated capacity groups : over 10k, 20k, 30k, 50k, 75k, 100k, below underground 200k, over underground 200k
- 3 types : general-type, low loss-type, amorphous-type

② The loss of the distribution transformers for 4 customer groups is calculated with the same algorithm of the primary feeders loss calculation.

③ The ratios of total selling power and selling power of each customer group is calculated with the same algorithm of the primary feeders loss calculation.

④ The total loss of the distribution transformers for 4 customer groups is calculated with the same algorithm of the primary feeders loss calculation.

5.3 Loss Calculation of Secondary Feeders

① Total line length for line types is calculated with getting total line length of model feeders from SOMAS data.

- 3 line types : single phase two-wire, single phase three-wire, three-phase four-wire (three-phase three-wire is included in this)
- Ratios for each line type : the ratios for each line type are calculated from the statistical data by connection and supply area of the distribution transformer.

② The following conditions are supposed to calculate the secondary feeders loss.

- The line size is 38 mm^2 for light load (one phase), and is 60 mm^2 for motor load (three phase).
- There are end-concentration and equal load distribution for the load distribution of the secondary feeders.

③ The average current of the secondary feeders is calculated in the following process.

- The number of transformer for 8 rated capacity groups of model feeders is calculated from SOMAS data.
- The peak power for 8 rated capacity groups is calculated with utilization factor per KVA.
- The average current for 8 rated capacity groups of model feeders is calculated with the above ratios.

④ The loss of the secondary feeders for 4 customer groups is calculated with the same algorithm of the primary feeders loss calculation.

⑤ The ratios of total selling power and selling power of each customer group are calculated with the same algorithm of the primary feeders loss calculation.

⑥ The total loss of the secondary feeders for 4 customer groups is calculated with the same algorithm of the primary feeders loss calculation.

5.4 Calculation of the Annual Loss Amount

① The distribution loss for 4 customer groups under peak load is calculated based on the primary feeders

② The number of primary feeders for 4 customer groups is calculated with the ratio of total number of primary feeders and the selling power of 4 customer groups.

③ Total loss for 4 customer groups under peak load is calculated with multiplying ① by ②

④ The loss load factor for 4 customer groups is calculated by Eq. (4)

⑤ Total loss amount is calculated with considering the loss load factor for 4 customer groups.

⑥ Annual total loss amount is calculated with multiplying summation of total loss amount by 8,760 (hour).

6. Results and Anaiysis

The simulations are made with the above algorithms, and the simulation results is explained as follows.

6.1 Selection of Model Feeder

6.1.1 Selection Result

To calculate the exact loss amount dependent on the reasonable and valid data, the model feeders are selected as shown in Fig. 3 with the cooperation from 15 distribution branches in KEPCO.

First, 65 distribution feeders are selected to calculate the loss factor, and 26 distribution feeders (9 for residential, 5 for commercial, 7 for industrial, 5 for rural) are selected to calculate the annual loss amount.

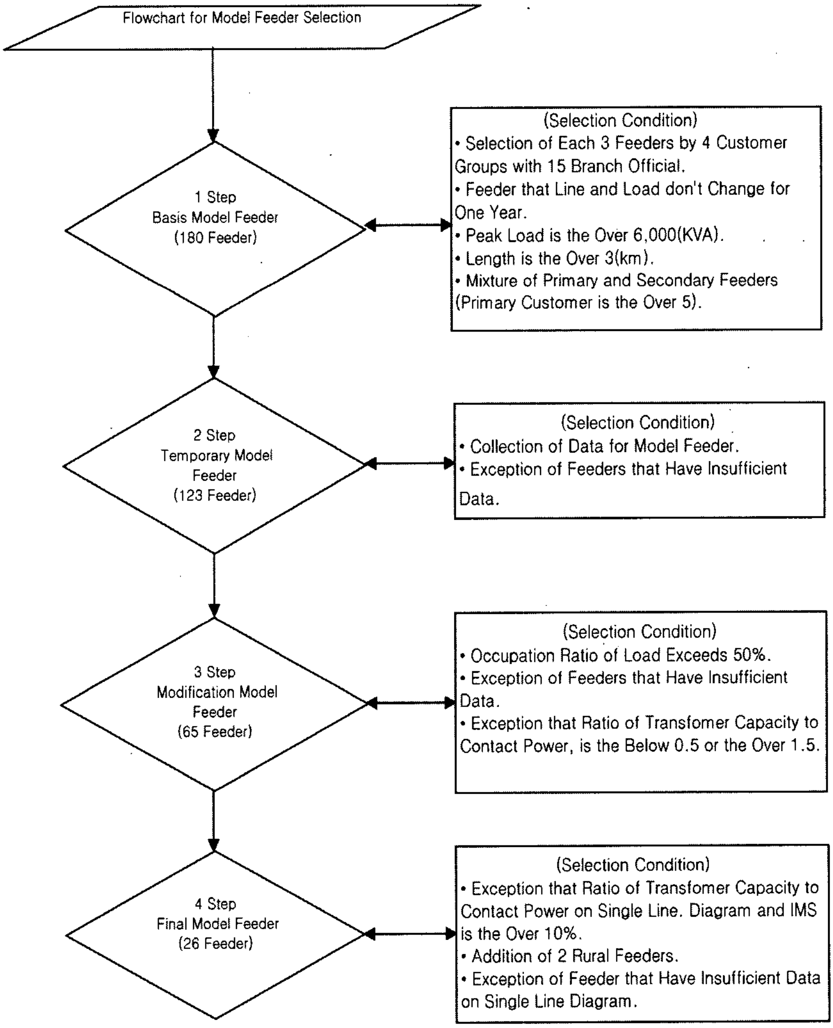


Fig. 3. Flowchart of the selection of model feeder

6.1.2 Modeling of Feeders

The modelling conditions are listed as follows

① If the type or size of feeder is different, the node is separated.

② The node is separated at the sending point of substation.

③ The power factor is assumed as 1.

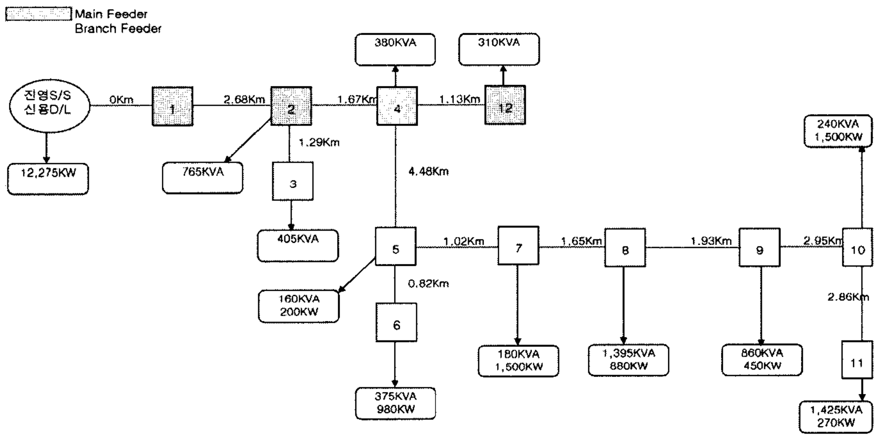
④ The branch nodes are separated after separation of the main feeders.

Using the modeling conditions, the feeder configuration and load distribution that are made with modeling the single line diagram of selected model feeders, are illustrated in Fig. 4.

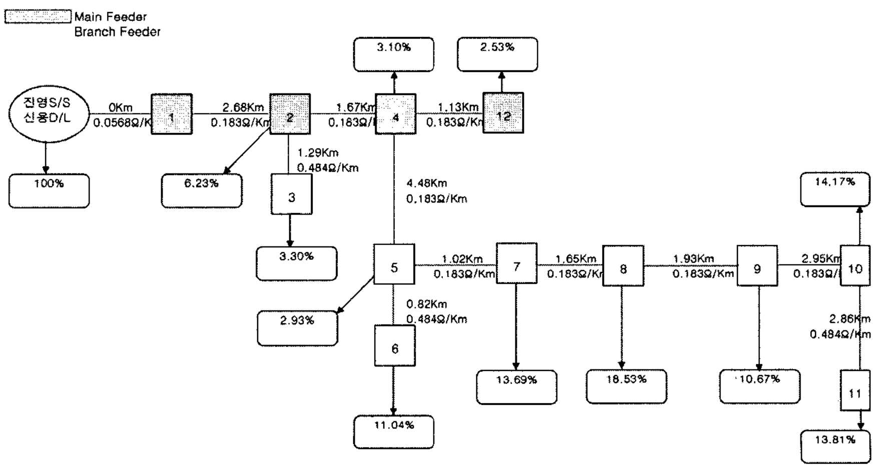
6.2 Recalculation of the Loss Factor

6.2.1 Calculation of the Loss Factor by Load Types

The loss factor for each customer group as shown in Table 2 is decided as one representative value, the arithmetic average is not large meaning. The decision methods of representative value that can reflect characteristics for each customer group, is explained as follows. In Table 2, the average value is calculated with dividing summed loss factor by the number of model feeders, the central value means the center when the loss factor is listed in a line from maximum value to minimum value, and the maximum frequent value means the average of the loss



(a) Feeder configuration



(b) Load distribution

Fig. 4. Feeder configuration and load distribution for SINYONG D/L, JINYOUNG S/S, PUSAN branch

Table 2. Representative value of the loss factor for 4 customer groups

	Average Value	Central Value	Frequency Value	Average of Normal Distribution
Residential	0.066901	0.060937	0.067832	0.0636
Commercial	0.099477	0.096732	0.084516	0.0995
Industrial	0.137438	0.143794	0.145911	0.1352
Rural	0.120021	0.127957	0.127645	0.1314

Table 3. Loss factor used the normal distribution average

	Loss Factor(k)				
	Average Value	Seasons			
		Spring	Summer	Fall	Winter
Residential	0.06298	0.073042	0.062319	0.073328	0.07549
Commercial	0.0996	0.110204	0.149321	0.115746	0.101266
Industrial	0.13191	0.135498	0.159476	0.162419	0.152606
Rural	0.12003	0.11869	0.04384	0.1047	0.14169

Table 4. Representative loss factor

	Loss Factor	Ratio of Selling Amount	Weight Application		Representative Value
Residential	0.0630	15.60%	16.81%	0.0106	0.1172
Commercial	0.1319	54.30%	58.52%	0.07719	
Industrial	0.0996	20.62%	22.22%	0.02213	
Rural	0.1200	2.27%	2.45%	0.00294	

factor that have the most frequency within some section, finally, the normal distribution average using the normal distribution and the standard deviation, takes the average for coefficient values within standard deviation extent from average of the loss factor. In calculation result of the loss factor, the industrial customer have the biggest representative value and rural, commercial, residential is appeared in order.

6.2.2 Calculation of the Loss Factor by Seasons

Table 3 shows the calculation result of the loss factor by seasons for 4 customer groups such as residential, industrial, commercial and rural load.

The value of the loss factor for 4 customer groups is smaller than 0.32 of existing value. Because the loss factor is decided by the load factor and the loss load factor, the change of LF is inevitable and this is a cause to decrease the loss factor when there is many differences between power consumption in the past and the present, also the load's pattern is changed.

6.2.3 Representative Loss Factor

In this study, the recalculation of the loss factor was performed by load types and seasons. With the calculation result, we propose the one representative loss factor for applying to the whole distribution feeders in KEPCO. Where, the representative loss factor is calculated by the weighted sum of each loss factor for 4 customer groups. Because the ratio of selling amount by contract types is 15.6% for residential, 20.62% for commercial, 54.3% for industrial, 2.27% for rural, table shows the representative

Table 5. Distribution loss by equipments.

	Primary Feeders (KW)	Distribution Transformer (KW)	Secondary Feeders (KW)	Total Loss (KW)
Residential	4.98	20.67	9.37	35.02
Commercial	2.91	24.36	3.83	31.09
Industrial	29.14	20.00	16.10	65.24
Rural	4.43	1.10	2.04	7.57
Total Loss	41.47	66.13	31.33	138.93
Percent	29.85%	47.60%	22.55%	100%

Table 6. Annual distribution loss amount by equipments

	Primary Feeders (GWh)	Distribution Transformer (GWh)	Secondary Feeders (GWh)	Total Loss Amount (GWh)
Residential	72.52	300.86	136.35	509.72
Commercial	39.20	327.98	51.51	418.69
Industrial	523.17	359.02	288.99	1,171.17
Rural	60.10	14.93	27.61	102.64
Loss Amount	694.97	1,002.79	504.46	2,202.22
Percent	31.56%	45.54%	22.91%	100%

loss factor calculated by the weighting factor considering each ratio.

6.3 Calculation of the Distribution Loss by Equipments

Table 5 is the simulation result for the distribution loss by equipment under peak load, and Table 6 is annual total distribution loss. The loss of industrial primary and secondary feeders occupying more than 50% in total primary feeders, takes absolute weight than other customer groups. But in the loss of distribution transformers, industrial primary feeders take similar value with commercial and rural primary feeders. On the other hand, Table 5 shows the loss ratios of each equipment, then, the annul loss ratios of each equipments are 30% for primary feeders, 48% for distribution transformers, and 22% for secondary feeders. To be concrete, the ratio of annul total distribution loss amount (2,202.2GWh) calculated with using the proposed algorithm and total selling power amount by contract types in 2002 (190,982.2GWh, direct trade consumer more than 10 MW is excepted), is about 1.15%. Though the proposed algorithm calculated the annual loss amount of primary feeders with single line diagram, the single-phase load of branch that don't appear on single line diagram, must be considered. The annual loss amount considered the ratio of single-phase load (32%) and three phases load (68%) is 3,238.5GWh, and the ratio of annul total distribution loss calculated with using the proposed algorithm and total selling power amount by contract types in 2002, is about 1.70%. Further, the above the annual total distribution loss amount is calculated for only 4 customer groups. Thus, if the occupation ratio (total 7.21%, 233.5GWh) of other contract types (educational, midnight, light) is considered, the above ratio becomes about 1.82%. Addition, if the loss amount of service lines, meters and leakage etc. is considered, the ratio of total distribution loss can be calculated.

7. Conclusions

To suggest an optimal method for the distribution loss calculation, this study developed algorithms for the selection of a model feeder, the calculation of the loss factor and the loss calculation by equipment. The results are summarized as follows.

① To calculate the precise loss amount dependent on the reasonable and valid data, 26 primary feeders were selected with the cooperation of 15 distribution branches in KEPCO. To verify the effectiveness of each selected model feeder, the number of samples by statistical method was proposed.

② To calculate the exact and reasonable loss factor, the loss factors for 4 customer groups (residential, industrial, commercial, rural) were calculated with 65 primary feeders. The representative loss factor of 0.12 which is calculated by algorithm presented in this paper was a smaller value than the existing value of 0.32.

③ To calculate the exact distribution loss amount, this study presented the calculation algorithm for the distribution loss by equipment such as primary feeders, distribution transformers and secondary feeders.

By using this algorithm and the newly-calculated loss factor, the effectiveness of proposed methods was verified since the simulation result (1.82%) is similar to the present (1.8%) in the distribution loss ratio.

In the future, we are going to improve the accuracy of the distribution loss calculation by using the data of the distribution automation and SOMAS.

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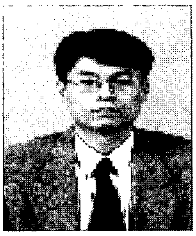

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