Optimal Calculation Method of Distribution Loss in Distribution Systems

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Abstract - Recently, the needs and concerns regarding power loss have been increasing according to energy conservation at the level of the national policies and the business strategies of power utilities. In particular, the issue of power loss is the main factor for determining rates for electrical consumption in the deregulation of the electrical industry. However, because of the lack of management for power loss load factors (LLF) it is difficult to make a calculation for power loss and to make a decision concerning the electric rates. Furthermore, loss factor (k-factor) in Korea, which is of primary significance in the calculation of 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 that have been selected by appropriate procedures. Based on the above, the algorithms and methods, as well as 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 demonstrate the effectiveness and usefulness of the proposed methods.

Keywords : Distribution loss, load factor, loss factor, loss load factor

1. Introduction

Recently, the issue of power loss is the main factor used for determining the price of electricity in the circumstances involving deregulation of the electrical industry. That is to say, the loss correction dependent on the location of the facility plays an important role in the power price that is fixed at 5 minute periods. 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 reach a consensus if precise and reliable basis data are not presented.

Distribution system loss refers to the power consumed by the electrical characteristics of equipments (in proportion to resister and the square of the current) while power is being supplied through primary feeders, distribution transformers, secondary feeders and service lines, from distribution substations to consumers. The total loss can be calculated easily by subtracting selling amount from supplying amount. However, it is difficult to perform calculation of the loss amount produced by each piece of equipment, because this requires computation of the loss load factor considering the load types, the loss factor and line constants, etc. The values currently in use are those that have been calculated by load characteristics and equipments in the 1960s. As such, there is a great need to recalculate considering the change of operation conditions such as power factor, step-up of voltage and newly-developed equipments.

The Korea Electric Power Corporation (KEPCO) has also 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 calculation algorithms for the distribution loss by load types and the loss load factor using statistical methods. To be specific, Chapter 2 explains the concepts for distribution loss and the problems during loss calculation. Chapter 3 shows the effectiveness of the model feeder, which is a most important factor in terms of calculation for the distribution loss. Chapter 4 presents the calculation algorithms for the loss factor using 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 and secondary feeders, and estimates the elements affecting the distribution loss by parameter analysis. Finally, Chapter 6

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shows the loss amount by equipment with the actual system and identifies the effectiveness of the proposed algorithms.

2. Concept of Distribution Loss

2.1 Definition of Distribution Loss

Power loss occurs while power is supplied from distribution substations to customers, and this distribution loss is expressed in kwh. The distribution loss is the difference between the power amount used by consumers and that sent in the distribution substation during a fixed period.

For example, if power is supplied from upper voltage level, and is sold to a consumer having a voltage level equal to a 220/380V distribution system, the energy supplied 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 both difficult and inefficient to calculate the distribution loss for all time intervals. Therefore, it is general procedure to calculate distribution loss with the loss load factor that has the 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 the relevant period is calculated through the loss load factor and the total loss amount can be decided by multiplying the average loss.

2.2.1 Load Factor (LF)

As stated above, the load factor of a 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 determined with measurement of actual load data and statistical analysis. This value has various characteristics by seasons and 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 and T : time interval.

As in the above equation, the loss factor, which is the most important factor in calculation for the distribution loss, must be calculated annually. But, KEPCO has been using the same value of 0.32 since the fiscal year of 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.

2. Selection of Model Feeder for the Distribution Loss Calculation

Because KEPCO has 6,631 primary feeders with a total line length of more than 1.64×10^8m, over 1.5 million distribution transformers, secondary feeders with a total line length of more than 1.88×10^8m, and service lines, etc. according to records dated November 2003; it is difficult to accurately calculate the distribution loss by equipments. Also, because the load amount and utilization factor by time interval of each piece of equipment is required to calculate annual distribution loss, it is almost impossible to calculate the distribution loss of all equipments individually.

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

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

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

where, N : number of samples by groups, P : total number of distribution feeders by groups, Z_a : presumption error for sample production and 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 determined to be greater in number than sample feeders, calculated statistically as shown in Table 1. First, 65 distribution feeders are selected to calculate the loss factor. Finally, 26 distribution feeders are chosen to calculate the annual loss amount.

Table 1 Selection of Sample Feeder

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

3. Calculation 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

$$LLF = \frac{L_{ave}}{L_{max}} = \frac{\sum I_{ave}^2}{I_{max}^2} \tag{7}$$

$$L_{ave} = I_{ave}^2 \times R \tag{8}$$

$$L_{max} = I_{max}^2 \times R \tag{9}$$

Where, I_{ave} and I_{max} indicate 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 the above method, the loss factor k can be calculated by relation among the load factor, the loss load factor, and 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.

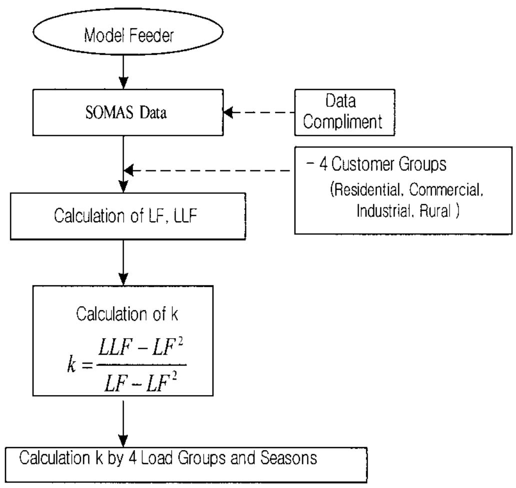


Fig. 1 Calculation algorithm for the loss factor

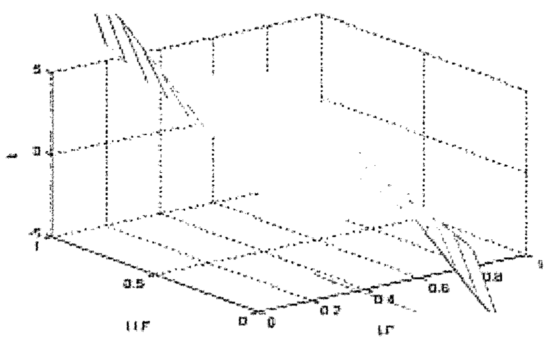


Fig. 2 Relation of loss factor, load factor and loss load factor

To understand characteristics for the loss factor, the interrelations between the load factor, the loss load factor and the loss factor are shown in Fig. 2 by a third dimension graph. If the loss load factor is constant, an increase in the load factor brings about a decrease in the loss factor. That is, the loss factor fluctuation according to the load factor has a big and a small value. If the load factor is constant, the change in the loss load factor in the case of steep slope brings about a big change in the loss factor. On the contrary, the change in the loss load factor in the case of gentle slope brings about a small change in 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 by Equipments

To calculate the exact distribution loss amount, this study presents a calculation algorithm for the distribution loss by equipment such as primary feeders, distribution transformers, secondary feeders, etc. To calculate the loss of primary feeders, a feeder configuration diagram and a load distribution diagram are prepared from a single line diagram of a 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 transformers and the number of transformers 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 feeder 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 feeder 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)
- Other losses = 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 loss are calculated by using the ratios of the total number of distribution transformers and the number of transformers 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 as that used in 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 as that used in the primary feeders loss calculation.

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

5.3 Loss Calculation of Secondary Feeders

① Total line length for line types is calculated by obtaining 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 believed to calculate the loss of the secondary feeders.

- The line size is 38 ㎟ for light load (one phase) and 60 ㎟ 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 transformers 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 as that used in the loss calculation of the primary feeders.

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

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

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 by multiplying ① with 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 by multiplying summation of total loss amount with 8,760 (hours).

6. Simulation Results and Analysis

The simulations are made with the above algorithms, and the simulation results are 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 of 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.

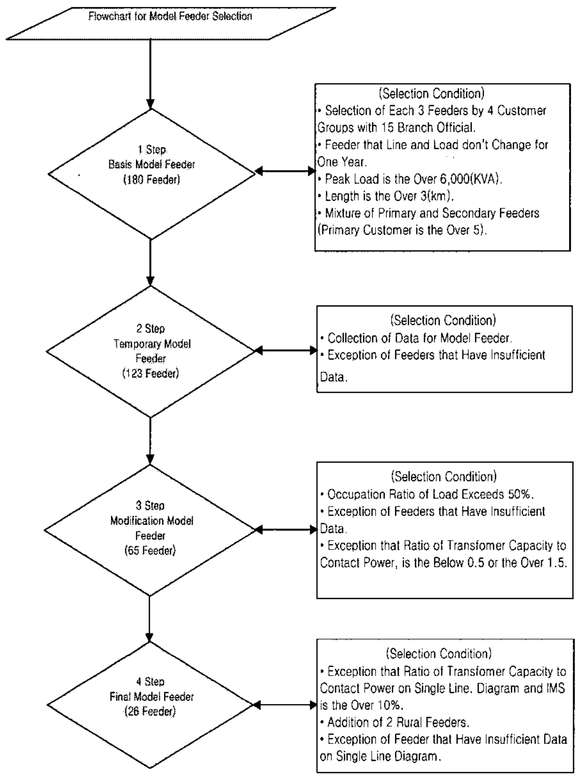


Fig. 3 Flowchart of the selection of model feeder

6.1.2 Modeling of Feeders

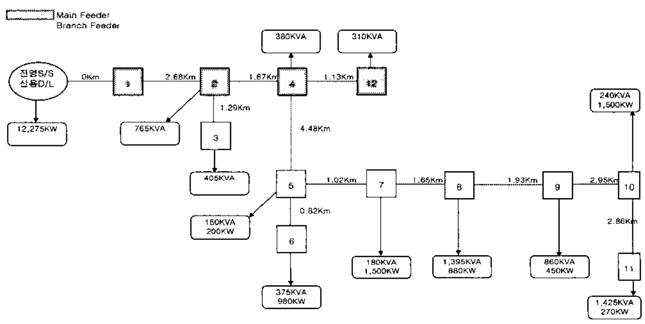
The modeling conditions are listed as follows

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

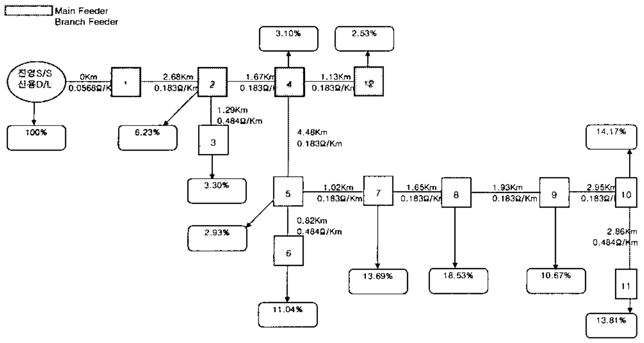
② The node is separated at the substation sending point.

③ The power factor is assumed as 1.

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



(a) Feeder configuration



(b) Load distribution

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

Using the modeling conditions, the feeder configuration and load distribution prepared by 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 significant in meaning. The decision methods of representative value that can reflect characteristics for each customer group are explained as follows. In Table 2, the average value is calculated by dividing summed loss factor by the number of model feeders. The central value signifies the center when the loss factor is listed in a line from maximum value to minimum value, and the maximum frequent value signifies the average of the loss factor that has the most frequency within some section. Finally, the normal distribution average using normal distribution and standard deviation, takes the average for coefficient values within standard deviation extent from average of the loss factor. In the loss factor calculation result, the industrial customers have the largest representative value, and rural, commercial and residential customers appear in order.

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

6.2.2 Calculation of the Loss Factor by Seasons

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

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

Table 3 Loss factor using 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

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 to be applied to all of the 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 4 shows the representative loss factor calculated by the weighting factor considering each ratio.

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	

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 all primary feeders, takes absolute weight over other customer groups. However, in the loss of distribution transformers, industrial primary feeders take similar value with commercial and rural primary feeders. On the other hand, Fig. 5 shows the loss ratios for each equipment type, in which the annul loss ratios are 30% for primary feeders, 48% for distribution transformers, and 22% for secondary feeders. To be concrete, the ratio of annual 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 10MW is accepted), is about 1.15%. Though the proposed algorithm calculated the annual loss amount of primary feeders with a single line diagram, the single-phase load of branch that doesn't appear in the single line diagram, must be considered. The annual loss amount considered the ratio of single-phase load (32%) and three phased load (68%) is 3,238.5GWh, and the ratio of annul total distribution loss calculated using the proposed algorithm and total selling power amount by contract types in 2002, is about 1.70%. Further, the above 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%. In addition, if the loss amount of service lines, meters and leakage, etc. is considered, the ratio of total distribution loss can be calculated.

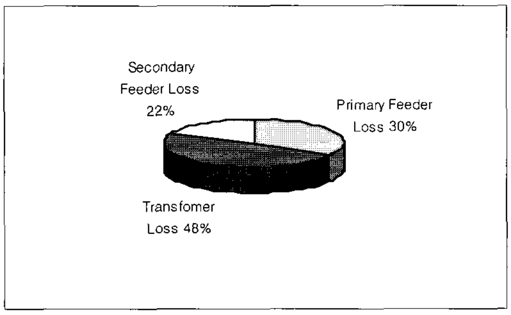


Fig. 5 Annual distribution loss amount by equipments

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%

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 factor of 0.12 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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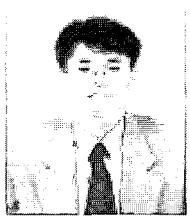

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