MULTI EVALUATION METHOD OF DISTRIBUTION NETWORK WITH DISTRIBUTED GENERATORS

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Abstract – In this paper, the authors propose a multi evaluation method to evaluate the distribution network configuration candidates satisfied with constraints of voltage and line current limit from two viewpoints ((1) distribution loss and (2) voltage imbalance rate). In the proposed evaluation method, after several high-ranking candidates with small distribution loss are extracted by combinatorial optimization method, each candidate is evaluated from the two viewpoints using EMTP (Electro-Magnetic Transients Program). The standard analytical model of the distribution network based on the practical data is constructed to multi evaluate the distribution network configuration candidates. The constructed model has 4 distribution substations, 72 feeders, 450 switches, 1,728 single-phase loads, and 54 distributed generators (DG). This model has 2^{450} configuration candidates. In order to examine the validity of the proposed evaluation method, the numerical simulations are carried out for a standard analytical distribution network model with DGs.

Keywords: Distributed generator, distribution network, multi evaluation, distribution loss, voltage imbalance rate, EMTP

1 INTRODUCTION

Since a distribution network with many feeders has many sectionalizing switches, there are huge radial network configuration candidates by changing states (opened or closed) of sectionalizing switches. Recently, total number of DGs such as photovoltaic generation system and wind power generation system connected to distribution network is drastically increased. The distribution network connected with many DGs must be operated keeping reliability of power supply and power quality. Therefore, the many configurations of the distribution network with the DGs must be evaluated multiply from various viewpoints such as distribution loss, voltage imbalance rate and so on. So far, several researches to reliably operate distribution systems with DGs have been proposed [1]-[17]. However, the configuration has not been evaluated from several viewpoints (e.g. distribution loss and electric power quality).

In this paper, the authors propose a multi evaluation method to evaluate the distribution network configuration candidates satisfied with constraints of voltage and line current limit from two viewpoints ((1) distribution loss and (2) voltage imbalance rate). In the proposed evaluation method, after several high-ranking candidates with small distribution loss are extracted by combinatorial optimization method to three assumed cases of total output of DG (0%, 15%, and 30% of total load), each candidate is evaluated from the two viewpoints using EMTP.

2 ANALYTICAL MODEL OF DISTRIBUTION NETWORK WITH DGS

A constructed standard analytical model of distribution network to evaluate the distribution loss and voltage imbalance of the distribution network is shown in Figure 1. This model has 4 distribution substations, 72 feeders, 450 switches, 1,728 single-phase loads, 54 DGs (photovoltaic generation systems), and 2^{450} distribution network candidates. The standard analytical model data based on practical power utilities data is shown in Table 1.

The standard analytical model uses data of the sending current and power factor in the residential area, industrial area, and commercial area that the electric power company had measured. The sending current of each load area is shown in Figure 2. Figure 3 shows the power factor of each load area. Output of three type DGs is shown in Figure 4. By connecting the three imbalance single-phase loads to each feeder, the imbalance of each feeder loads are modeled.

Each single-phase load is modeled as a impedance load which consists of a resistance load R, an inductive load L, and a capacitive load C as shown in Figure 1.

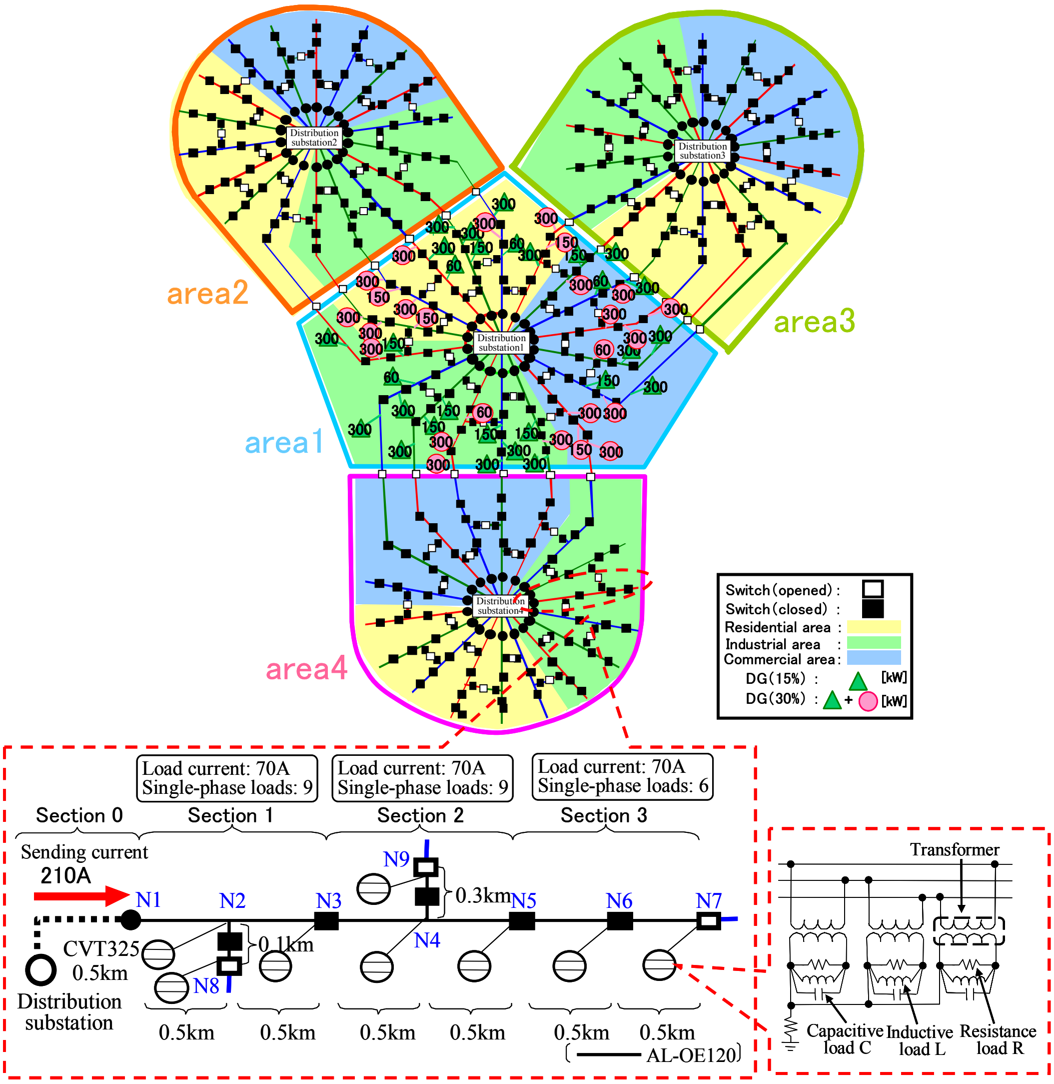

Figure 1: Standard analytical model of distribution network.

Number of distribution substations	4
Number of banks	3/substation
Number of feeders	72
Number of switches	450
Number of distribution network configuration candidates	2^{450} ($\approx 2.9*10^{135}$)
Number of single-phase loads	1,728
Number of DG	Case1: 0 PV Case2: 29 PVs Case3: 54 PVs
Total load of system	2,805MWh
Number of load areas	Residential : 4 Industrial : 4 Commercial : 4
Sending line voltage	6,600V
Maximum sending current	max210A/feeder
Feeder length	3.5km/feeder

Table 1: Standard analytical model data.

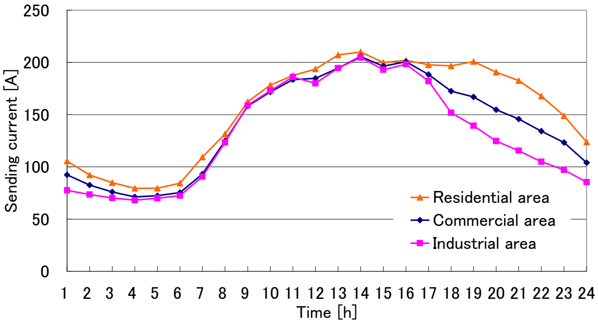

Figure 2: Sending current of each load area.

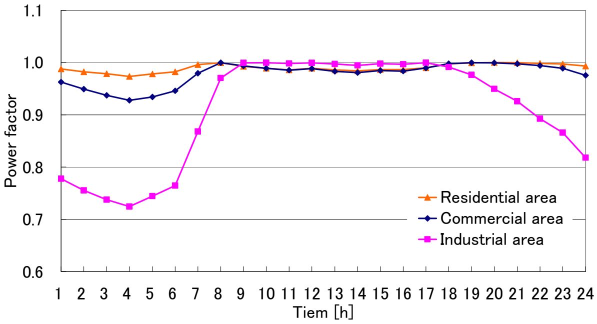

Figure 3: Power factor of each load area.

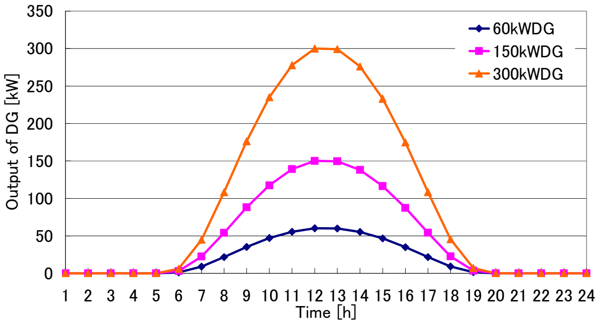

Figure 4: Output of DG.

3 MULTI EVALUATION METHOD FOR DISTRIBUTION NETWORK CONFIGURATION CANDIDATES

The multi evaluation proposed method has three procedures. The procedures of the proposed method of distribution loss and voltage imbalance rate for many configuration candidates are described below.

[Procedure 1] Distribution configuration candidates that are satisfied operation constraints (radial structure constraint, voltage drop constraint, and line capacity constraint) are selected. And then, several high-ranking candidates with small distribution loss at peak load are extracted by using ROBDD (Reduced Ordered Binary Decision Diagram) which is an efficient enumeration method [18][19] to three assumed cases of total output of DG (0%, 15%, and 30% of total load).

[Procedure 2] The selected candidates are evaluated from viewpoints of total distribution loss and voltage imbalance rate. If the voltage imbalance rate of the configuration candidate exceeds the upper limit value (3%), the configuration candidate is removed from the preferable configuration candidate.

[Procedure 3] The selected candidates are evaluated from a viewpoint of total balance. The configuration candidate with minimum evaluated value of total balance is determined as the best distribution network configuration.

Figure 5 shows the flow of multi evaluation for network configuration candidates. Each evaluation method from a viewpoint of distribution loss, voltage imbalance rate, and total balance is shown below.

3.1 Evaluation of Distribution Loss

The candidates are evaluated from a viewpoint of the distribution loss by calculating the distribution loss for several time periods in all feeders. The evaluation formula is expressed by

$$LOSS_N = \sum_{t=1}^{T}\sum_{f=1}^{F}\sum_{j=1}^{J}(I_{Utfj}^2 + I_{Vtfj}^2 + I_{Wtfj}^2)R_j \qquad (1)$$

where, $LOSS_N$ [Wh] is total distribution loss of candidate $N(=1\sim M)$, I_{Utfj}, I_{Vtfj}, I_{Wtfj} [A] are each phase node section $j(=1\sim J)$ current in feeder $f(=1\sim F)$ at $t(=1\sim T)$[h], and R_j [Ω] is line resistance of between nodes section j.

The candidate with the minimum value of Eq. (1) is evaluated as the best configuration from a viewpoint of the distribution loss.

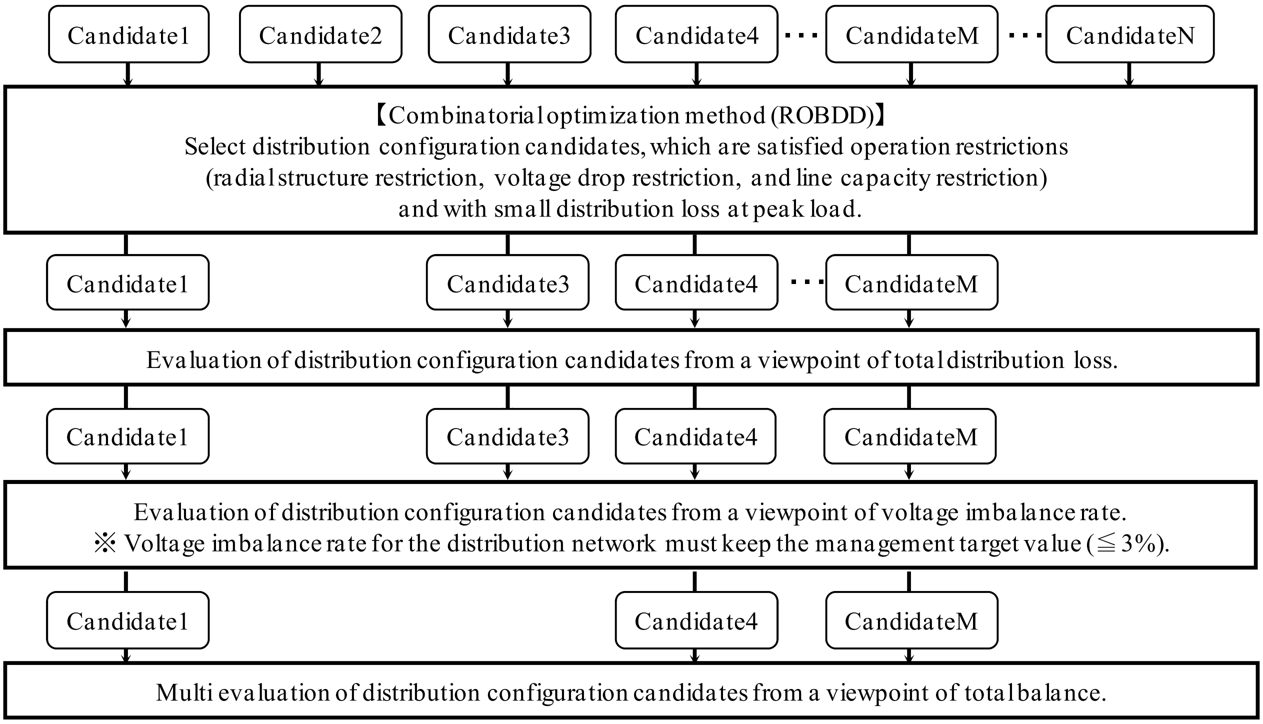

Figure 5: Flow of multi evaluation for network configuration candidates.

3.2 *Evaluation of Voltage Imbalance Rate*

The candidates are evaluated from a viewpoint of the voltage imbalance rate by calculating the maximum value of the voltage imbalance rate in all feeders, all nodes, and for several time periods. The evaluation formula is expressed by

$$U_{\max N} = \max_{t,f,i}\left\{\frac{|\dot{V}_{Utfi} + \dot{a}^2\dot{V}_{Vtfi} + \dot{a}\dot{V}_{Wtfi}|}{|\dot{V}_{Utfi} + \dot{a}\dot{V}_{Vtfi} + \dot{a}^2\dot{V}_{Wtfi}|}\times 100\right\} \qquad (2)$$

where, U_{maxN} [%] is maximum value of voltage imbalance rate of candidate N, $\dot{V}_{Utfi}$, $\dot{V}_{Vtfi}$, $\dot{V}_{Wtfi}$ [V] are U, V, W phase voltage vector at node i of feeder f at t[h], and $\dot{a}$ is vector operator ($\dot{a} = -1/2 + j\sqrt{3}/2$).

The candidate with the minimum value of Eq. (2) is evaluated as the best configuration from a viewpoint of the voltage imbalance rate.

3.3 *Evaluation of Total Balance*

In this paper, the candidates are evaluated from above two viewpoints using 2-norm. The evaluation values obtained by Eq. (1) and Eq. (2) are normalized from 0.1 to 1 (minimum value is 0.1, maximum value is 1), respectively. And the candidates are evaluated according to the evaluation index of total balance:

$$E_N = \sqrt{{L_N}^2 + {U_N}^2} \qquad (3)$$

where, L_N is normalized distribution loss of candidate N, and U_N is normalized maximum value of voltage imbalance rate of candidate N.

The candidate with the minimum value of Eq. (3) is evaluated as the best configuration from a viewpoint of the total balance.

4 NUMERIC EXAMPLES

The simulation is carried out using the analytical model of Figure 1 as an example of numerical calculation. In the analytical model of the distribution network, the candidates are evaluated from viewpoints of the distribution loss, the voltage imbalance rate, and the total balance based on the proposed method. This model has 2^{450} candidates. In this paper, 50 high-ranking candidates with small distribution loss at peak load are extracted from among these huge candidates by using ROBDD. The evaluation results of the distribution network configuration candidates are shown in Figure 6-14.

The total distribution loss for each configuration in each case (total output of DGs is 0%, 15%, and 30% of total load) is shown in Figure 6-8, respectively. The best configuration without DG obtained from a viewpoint of the distribution loss is candidate 5 ($LOSS_5$ =48,358kWh). When total output of DGs is 15% of total load and total output of DGs is 30% of total load, the best configuration obtained from a viewpoint of the distribution loss is candidate 1 ($LOSS_1$=46,480kWh, 44,927kWh). From Figure 6-8, it is seen that total distribution loss is decreases by increasing of total output of DG.

The maximum value of voltage imbalance rate for each configuration is shown in Figure 9-11. The best configuration without DG obtained from a viewpoint of the voltage imbalance rate is candidate 9 (U_{max9}=2.86%) and it is seen that all candidates satisfy the management target value (3%). When total output of DGs is 15% of total load, the best configuration obtained from a viewpoint of the voltage imbalance rate is candidate 37 (U_{max37}=2.76%). When total output of DGs is 30% of total load, the best configuration obtained from a viewpoint of the voltage imbalance rate is candidate 1 (U_{max1}=2.95%) and it is seen that some candidates do not satisfy the management target value (3%). When a number of best configuration candidates with same value of the voltage imbalance rate exist, the candidate with the smallest distribution loss is determined as the best configuration.

The total evaluation value for each configuration is shown in Figure 12-14. The best configuration without DG obtained from a viewpoint of the total balance is candidate 9 (E_9=0.21). When total output of DGs is 15% of total load, the best configuration obtained from a viewpoint of the total balance is candidate 37 (E_{37} =0.63). When total output of DGs is 30% of total load, the best configuration from a viewpoint of the total balance is candidate 1 (E_1=0.14).

The best configuration obtained from a viewpoint of the total balance is shown in Figure 15-17. From these figures, it is seen that the best configuration changes with differences in the total output of DGs.

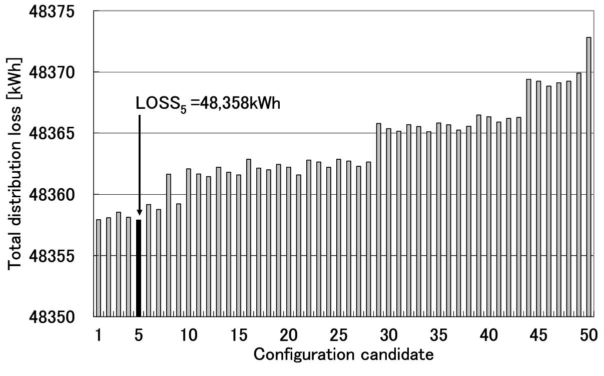

Figure 6: Total distribution loss for each configuration candidate without DG.

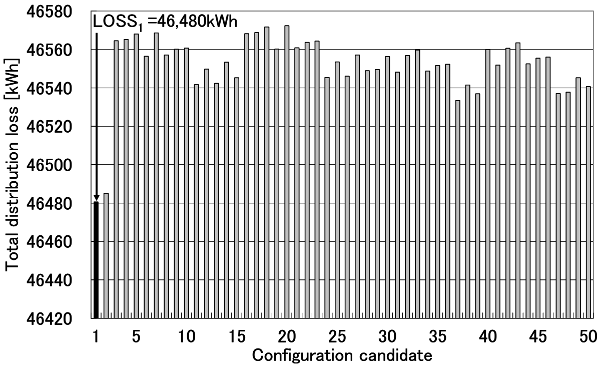

Figure 7: Total distribution loss for each configuration candidate when total output of DGs is 15% of total load

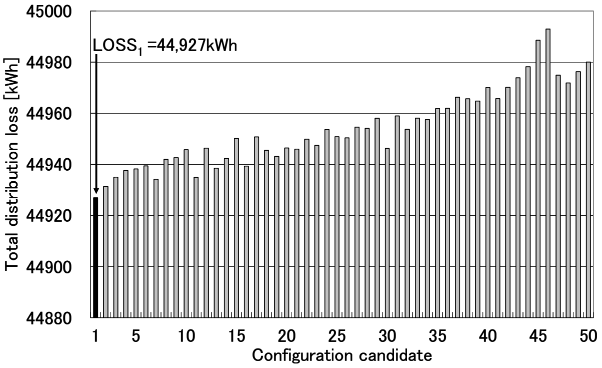

Figure 8: Total distribution loss for each configuration candidate when total output of DGs is 30% of total load

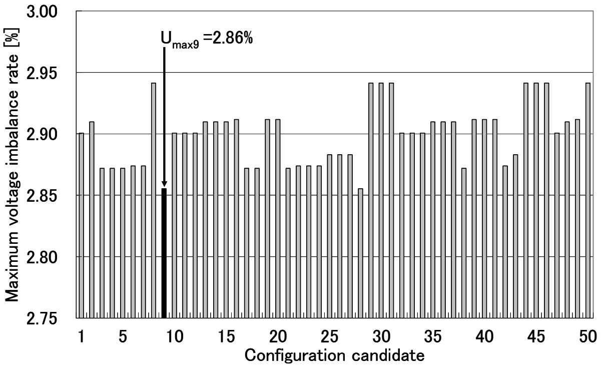

Figure 9: Maximum value of voltage imbalance rate for each configuration candidate without DG.

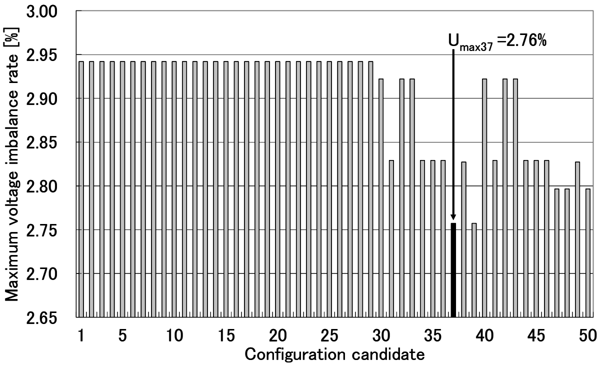

Figure 10: Maximum value of voltage imbalance rate for each configuration candidate when total output of DGs is 15% of total load.

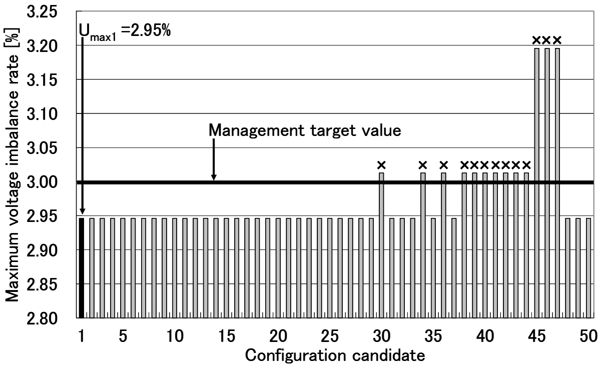

Figure 11: Maximum value of voltage imbalance rate for each configuration candidate when total output of DGs is 30% of total load.

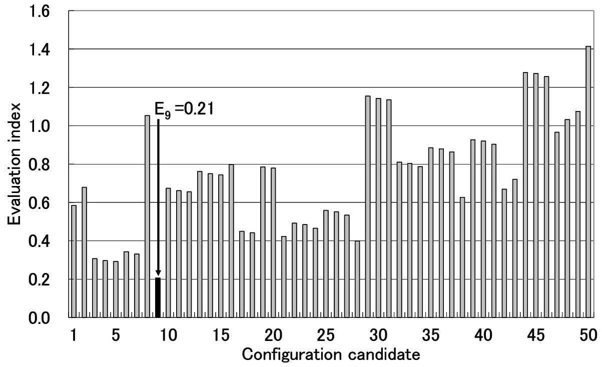

Figure 12: Total evaluation value for each configuration candidate without DG.

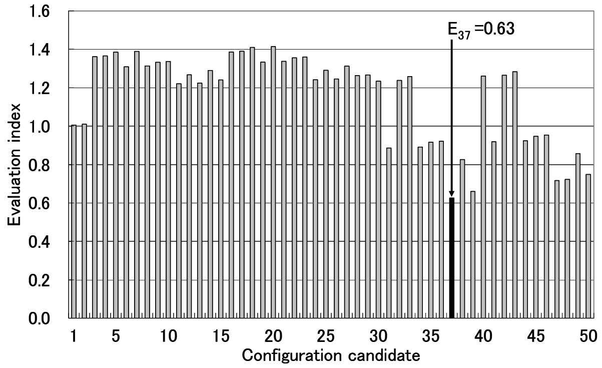

Figure 13: Total evaluation value for each configuration candidate when total output of DGs is 15% of total load.

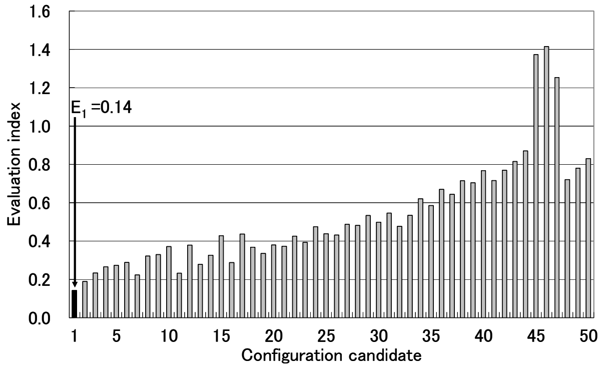

Figure 14: Total evaluation value for each configuration candidate when total output of DGs is 30% of total load.

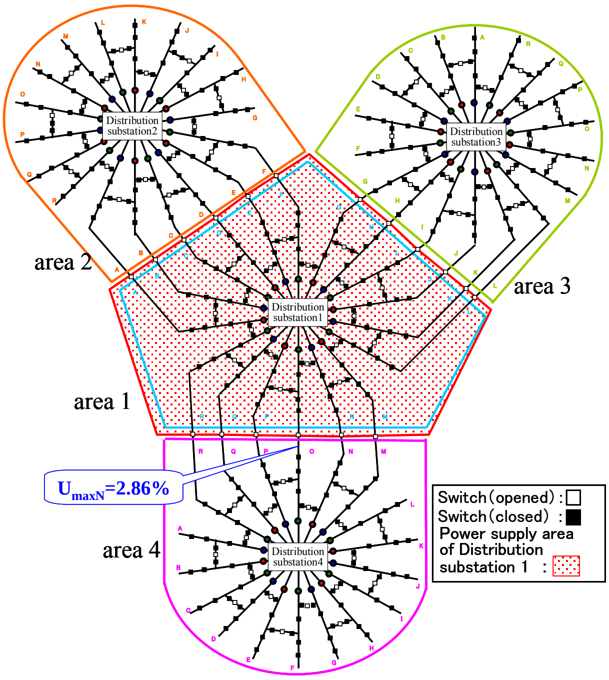

Figure 15: The best configuration without DG.

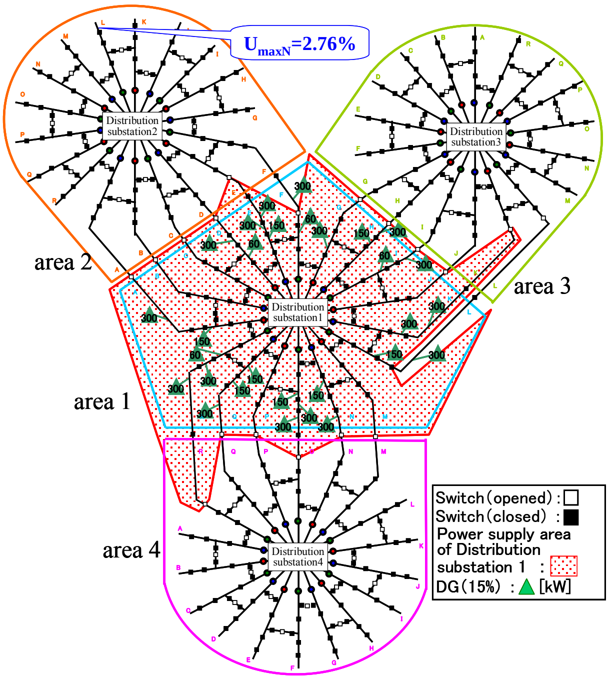

Figure 16: The best configuration when total output of DGs is 15% of total load.

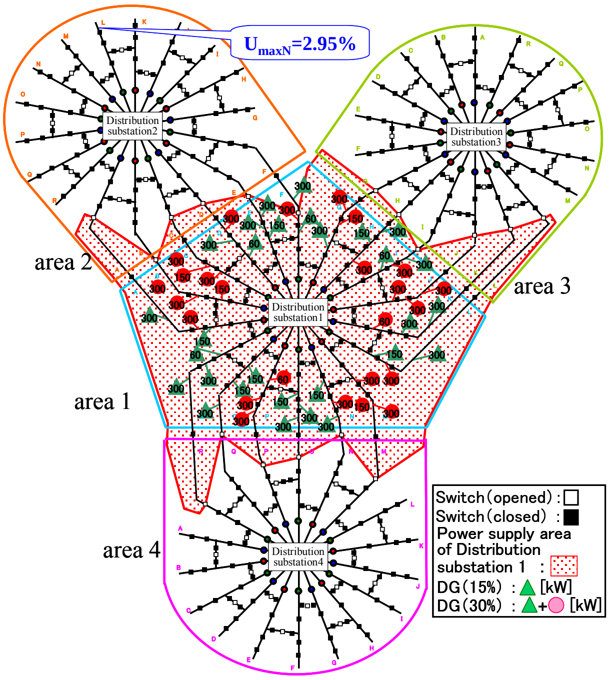

Figure 17: The best configuration when total output of DGs is 30% of total load.

5 CONCLUSION

In this paper, the authors proposed an evaluation method to evaluate the distribution network configuration candidates from two viewpoints (distribution loss and voltage imbalance rate). In order to examine the validity of the proposed method, the numerical simulations were carried out using EMTP for the constructed standard analytical distribution network model with 2^{450} configuration candidates based on the practical data. In the proposed method, after 50 high-ranking candidates with small distribution loss at peak load were extracted in three assumed cases of total output of DG (0%, 15%, and 30% of total load), each candidate was evaluated from the two viewpoints and the best configuration was obtained.

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