Voltage Profile improvement and Loss Reduction in LV Distribution network using Genetic Algorithm

O. O. Osaloni, A. S. Akinyemi

Abstract— This paper investigates the use of Genetic algorithm to find the optimal size and location of distributed generation units to address voltage profile and power loss in a Low distribution system. The total active and reactive power losses are minimized and voltage profile is improved. GA fitness function is introduced, including the active power losses, reactive power losses and the cumulative voltage deviation variables with selecting the weight of each variable. GA fitness function is subjected to Voltage Constraints, active and reactive power losses constraints and DG size constraint.

Index Terms— Genetic Algorithm, Distributed Network, Distributed Generation, Loss reduction, voltage profile improvement.

1 INTRODUCTION

Due to climate change and the increasing demand for clean energy, the use of distributed generation (DG) is drawing more attention worldwide. DG stands as one of the best option for the application of renewable energy sources and a better way of solving increase energy demand. DG provides voltage support to large–scale distribution, reliability improvement and reduction loss in the power system. DG technology has become a hot research topic, given the increasing global concerns about environmental protection, energy conservation, and increasing sophistication of wind power, photovoltaic power generation and other renewables energy technologies [1]. However, there are some other issues which should be analysed before maximizing their technical benefits such as voltage rise issues, reverse power flow, etc. As a result, integration of Distributed Generation with distribution network offers a promising solution such as diversity, flexibility, reliability, etc. [2] Therefore, an intensive level of research is needed to understand the impact of distributed generation on distribution system. From previous studies, it has been seen that different penetration level and various placement of DG will impact the distribution system differently [1].
The planning of the electric system with the presence of DG requires several factors to be taken into considerations, such as; the best technology to use, the number and the capacity of the units, the best location, and type of network connection, etc. [2]. Therefore, detail and exact analysis method is required to determine the more accurate and precise location and size of DG. In distributed system, DG should be allocated in an optimal way such that it will reduce system losses and hence improve the voltage profile. The selection of the best place for installation and the preferable size of the DG unit in large distribution system is a complex combinatorial optimization problem [3]. This paper is arranged as follows; section 2 presents the definition of DG. Section III describes distribution losses with the variation of DG size and location. Section IV discusses the methodology of this paper and previous methods. Objective of our analysis is given in Section V. In Section VII, the main constraints in the optimization process in the methodology was discussed, VIII presents the simulation results and discussion of findings. Evaluation of estimated performances have been analysed and compared.

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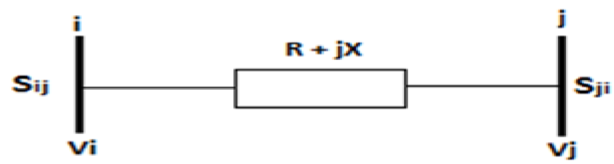
2. DISTRIBUTED GENERATION

Detailed Generally, distributed generation means the electric power generation within distributed network to fulfil the rapid energy demand of consumers. However, distributed generation can be defined in a variety of ways.
1) The Electric Power Research Institute (EPRI) defines distributed generation as generation from 'a few kilo-watts up to 50 MW' [4].
2) International Energy Agency (IEA) defines distributed generation as generating plant serving a customer on-site or providing support to a distribution network, connected to the grid at distributed level voltages [5].
3) The International Conference on large High Voltage Electric Systems (CIGRE) defines DG as 'smaller than 50-100 MW' [4].

3. DISTRIBUTION LOSSES WITH THE VARIATION OF THE DG SIZE AND LOCATION.

In a distribution system power loss varies with numerous factors. Real power losses of a distribution system depend on the resistance of distribution lines, core losses of transformers and motors. As dielectric and rotational losses are so small compared with line losses. In this paper, only line losses are considered in this analysis. The power loss is illustrated using the complex power as shown the figure 1



The complex power S_{ij} from node i to j and S_{ji} from node j to i are;

$$S_{ij} = V_i I_{ij}^* \quad 1$$

$$S_{ij} = V_i I_{ij}^* \quad 2$$

Where, V_i and V_j are the voltages at node i and j respectively. The line current I_{ij} which is measured at bus i in the positive direction of i to j and I_{ji} which is measured at bus j in the positive direction of j to i Therefore, power loss in any line between node i and j can be written as the algebraic sum of power flows determined from (1) and (2) [6].

$$S_{Lij} = S_{ij} + S_{ji} \quad 3$$

After any converged load flow, power loss in any line can be calculated using (3) and taking the summation of all line losses, total power loss of the network can be calculated using equation (4) where n is the number of lines.

$$Loss = \sum_{K=1}^{n} S_L(k) \quad 4$$

For any distribution system, placement of any DG unit will change the power loss profile of that system. Actually, in a distribution network, power loss curve with the variation of power generation at a particular location is approximately quadratic function because Line Losses $\propto I^2R$ and $I \propto S$ considering I is the line current, R is the resistance, and S is the apparent power flowing through the line [7]. Therefore, as the DG size is increased in any location of a power distribution network, the total system losses are reduced to a minimum value. With further increasing of DG, losses again start to increase. This trend of losses with DG size variation is given in Fig. 2 for a test case to demonstrate the sizing and location issues of DG. Here, for DG size $P_{DG2,}$ we get the minimum power loss which is called optimum DG size for that bus.

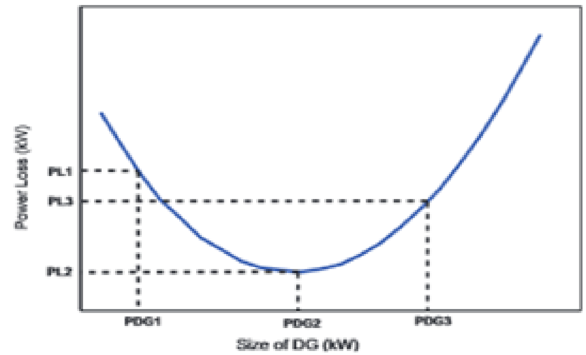


Figure. 2. Power loss characteristic of distribution system with DG size variation

A good number of research work is ongoing regarding DG integration with grid [9]. However, only a few studies have been done on DG sizing and allocation issue. Different methodologies to determine optimum location and size have been discussed in different literatures [10] [11] [12] [13]. Similar approach can be performed in DG allocation to reduce system power loss. In [10], authors have used this analytical method and rule of thumb for analysing the distribution system which is radial and has uniformly distributed loads. Rule is simple and easy to use but it cannot provide the proper solution when the load distribution type is changed. Moreover, it cannot be applied in meshed network.

4. GENETIC ALGORITHM

Genetic Algorithm is a general-purpose search techniques based on principles inspired from the genetic and evolution mechanisms observed in natural systems and populations of living beings. Their basic principle is the maintenance of a population of solutions to a problem (genotypes) as an encoded information, with the individuals that evolve in time [8].

Generally, GA comprises three different phases of search: Phase 1: creating an initial population; phase 2: evaluating a fitness function; phase 3: producing a new population. A genetic search starts with a randomly generated initial population within which each individual is evaluated by means of a fitness function. Individual in this and subsequent generations are duplicated or eliminated according to their fitness values. Further generations are created by applying GA operators. This eventually leads to a generation of high performing individuals [9].

There are usually three operators in a typical genetic algorithm, the first is the production operator (elitism) which makes one or more copies of any individual that possess a high fitness value; otherwise, the individual is eliminated from the solution pool; the second operator is the recombination (also known as the 'crossover') operator. This operator selects two individuals within the generation and a crossover site and carries out a swapping operation of the string bits to the right hand side of the crossover site of both individuals. Crossover operations synthesize bits of knowledge gained from both parents exhibiting better than average performance. Thus, the probability of a better offspring is greatly enhanced;

the third operator is the 'mutation' operator. This operator acts as a background operator and is used to explore some of the invested points in the search space by randomly flipping a 'bit' in a population of strings. Since frequent application of this operator would lead to a completely random search, a very low probability is usually assigned to its activation.

5. PROBLEM FORMULATION

The main goal of our analysis is to determine optimum size and location of dispersed generation so that it can reduce the real power loss in a distribution system. This analysis is important for efficient power system planning and operation. Distributed generation not only reduces the power loss of a system but also improves the voltage profile. However, inappropriate size and allocation of DG can cause low or over-voltage in the distribution system [10]. Therefore, another goal of our analysis is to check whether the voltage profile remains within permissible limit.

5.1 Objective Function Formulation

A precise evaluation for the Objective Function has been selected. The main goal of the algorithm is to determine the best locations and size for new Distributed Generation resources by minimizing different function, related to project aims. Two main goals are taken into considerations to determine the Objective Formula used in point of start: Power Losses reduction and voltage profile improvement. The Fitness Function is determined as following:

$$F = W_p P_{LR} + W_q Q_{LR} + W_v CVD$$

Where:

P_{LR} : Active Power Loss Reduction

Q_L : Reactive Power Loss Reduction

CVD : Cumulative Voltage Deviation

F: Fitness Function.

The active and reactive power losses are obtained from load flow program as follows.

$$P_{LR} = \frac{P_{loss} - P_{loss}^{DG}}{P_{loss}} 100\%$$

$$Q_{LR} = \frac{Q_{loss} - Q_{loss}^{DG}}{Q_{loss}} 100\%$$

Where:

P_{loss}, & Q_{loss} = Power loss of the system before introducing DG.

P_{loss}^{DG}, & Q_{loss}^{DG} =Power loss of the system after adding DG

The cumulative voltage deviation norm is defined as the normalized sum of the deviations of the obtained value from the desired value at every node on the feeder. The desired value being 1.0 p.u and the obtained value is the value from the three-phase distribution power flow [11]. In this work the CVD is determined as follows;

$$CVD = |\textstyle\sum_i^n (1 - V_i)|$$

Where:

n : The total number of nodes

$W_p, W_q, and\ W_v,$ are the objective function weights (Active, Reactive power losses and Cumulative Voltage Deviation weight) subjected to:

$$W_p + W_q + W_v = 1$$

The Constraints, Bus Voltage limits and DG Capacities are discussed below.

6. CONSTRAINTS

The main constraints in the optimization process in the methodology can be categorise to be the equality and inequality constraints. They are:

Equality Constraints $g_i(x) = 0$

Real and Reactive power balance constraints are related to the non-linear power flow equations. The power balance constraints is formulated as follows

$$P_i = P_{DGi} - P_{Di}$$
$$Q_i = Q_{DGi} - Q_{Di}$$

Inequality Constraints $h_j(x) \geq 0$

The inequality constraints are those associated with the bus voltages and DG. Inequality Constraints lies between acceptable limits to satisfy the objective function

6.1 Bus Voltage limits

This includes the upper and lower voltage magnitude limit, V_{imin} and V_{imax} at bus-i i e $\pm 5\%$. Bus Voltage magnitude is to be kept within acceptable operating limits throughout the optimization process, then the bus voltage limit is given by

$$V_{imin} \leq V_i \leq V_{imax}$$

6.2 DG Capacities

The Capacity of each DG unit should be differ around its nominal value, so that each DG unit must be maintained with in an acceptable limit. This includes the upper and lower real and reactive power generation limits of distributed generators (DGs) connected at bus-i. The capacity of DG is given as follow

$$P_{DGmin} \leq P_{DGi} \leq P_{DGmax}$$

$$Q_{DGmin} \leq Q_{DGi} \leq Q_{DGmax}$$

7. TEST SYSTEM DETAILS AND SIMIMULATION RESULTS

The test system for the case study is radial distribution system with 33 buses, 5 tie-lines (looping branches), as shown in Figure 2. The load data are given in Table AI and branch data in Table AII [13].

The initial statuses of all the sectionalizing switches (switches No. 1-32) are closed while all the tie-switches (switch No.33-37) are opened. The total loads for this test system are 3,715 kW and 2,300 kVAr. The current carrying capacity of branch No.1-9 is 400 A, and the other remaining branches including the tie lines are 200 A. To ensure fair comparison the number of DGs to be optimally located and sized is of three types:-DG that generates Active, Reactive and Active Reactive power.

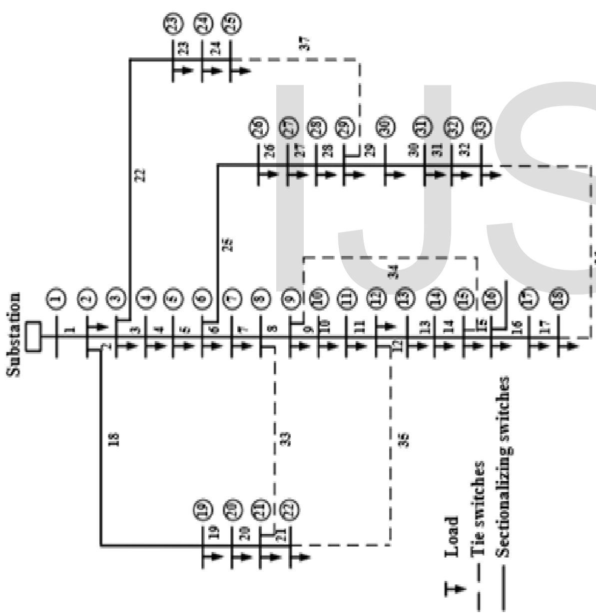


Figure 3. Test system of 33-bus radial Distribution.

The base case of the test system was carried out using Newton Rapson load flow technique to determine the total losses across the branches and voltage profile of the test system. Figure 4 shows that the voltage profile is below the permissible voltage level while figure 5 shows high power loss on the network.

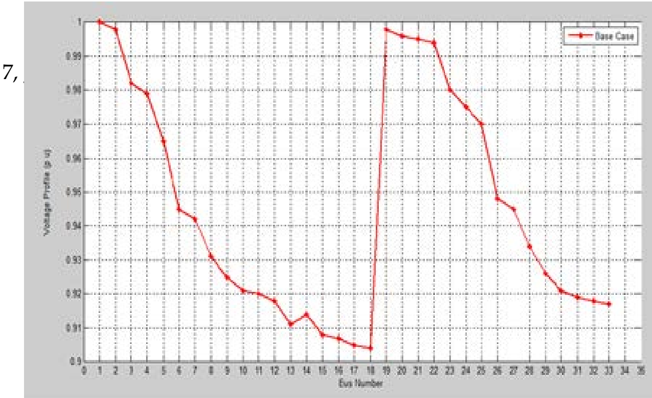


Figure 4: Voltage profile of 33 buses network before placement of DG.

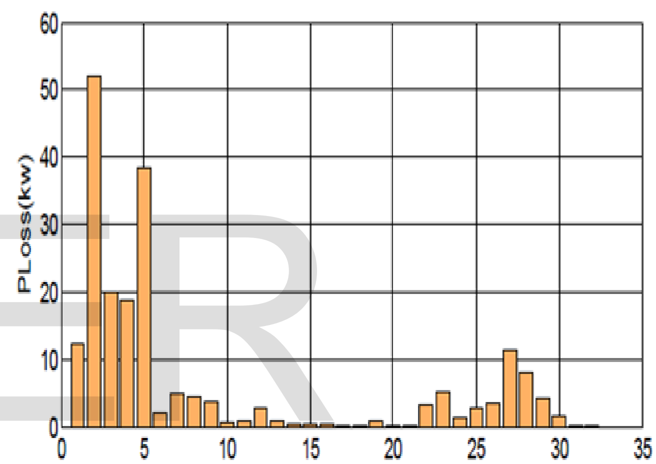


Figure 5: Losses in each line of 33 buses network before placement of DG.

7.1 Optimal Placement of DG type 1 (Just Generate Active Power)

This type DG just is able to generate active power in the network. Some technologies such as photovoltaic and fuel cells are capable to generate active power. Results obtained from utilizing the G A on the 33 buses network and DG type 1 is in this form that by installation of DG in bus number 7 with generated active power of 1.8578 megawatts, which means that the network total losses will fall from 202.68 kW to 110.24 kW. The curve of voltage profile and losses in each line of 33 buses network after placement of DG type 1 in bus number 7 of the network is figures 6 and 7.

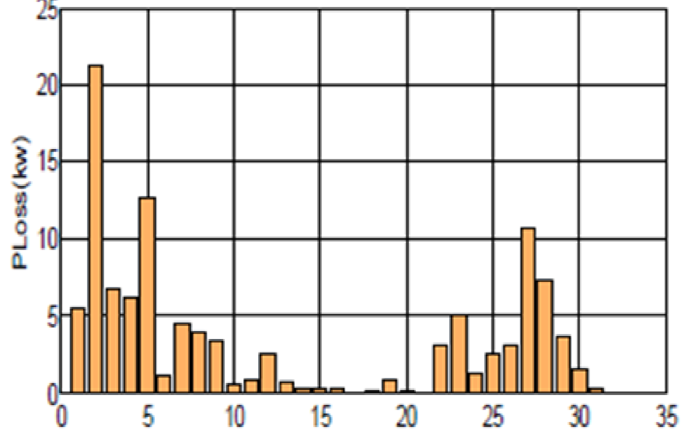


Figure 6: Losses in each line of 33 buses network after placement of DG type 1

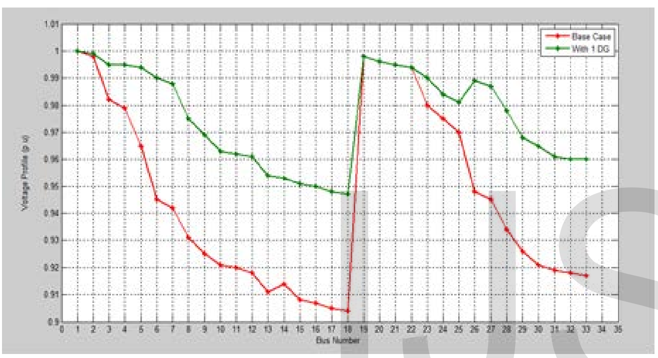


Figure 7: Voltage profile of 33 buses network after placement of DG type 1

7.2 Optimal Placement of DG type 2 (Just Generate Reactive Power)

This type of DG generates reactive power in the network. Technologies such as synchronization and synchronization condenser compensators are able to generate reactive power. Results of the genetic algorithm on 33 buses network and DG type 2 shows that by installation of DG in bus number 29 with 1.2248 megawatt generative reactive power, the total losses of network will decrease from 202.68 kilo watt to 145.55 kilo watt. The curve of voltage profile and 33 buses network losses after placement of DG type 2 in bus 29 is as the figures 8 and 9.

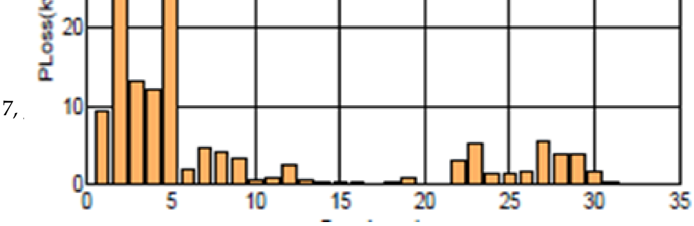


Figure 8: Losses in each line of 33 buses network after placement of DG type 2

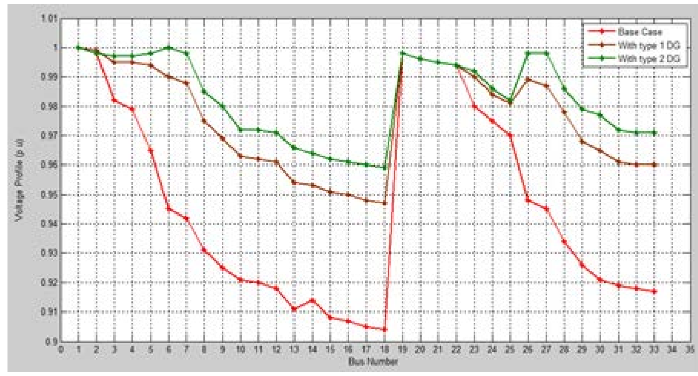


Figure 9: Voltage profile of 33 buses network after placement of DG type 2

7.3 Optimal Placement of DG type 3 (Generate Active and Reactive Power)

This type of DG is able to generate active and reactive power in the network. Technologies such as synchronization machines are able to generate reactive and active power. The results obtained from performing the genetic algorithm in 33 buses network and DG type 3 shows that by the installation of DG in bus number 30, the network total losses will decrease from 202.68 kilo watt to 64.75 kilo watt. The curve of voltage profile and losses in each line of 33 buses network after placement of DG type 3 in bus number 29 is as figures 10 and 11.

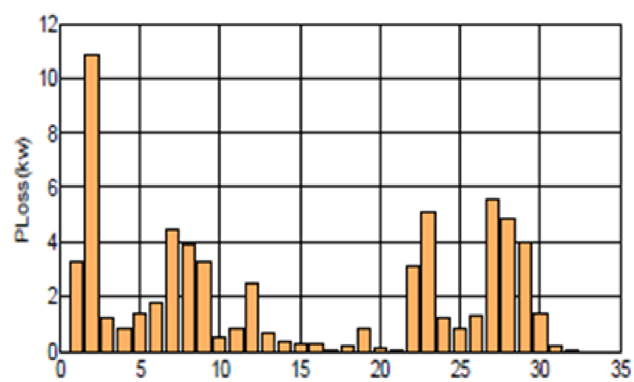


Figure 10: Losses in each line of 33 buses network after placement of DG type 3

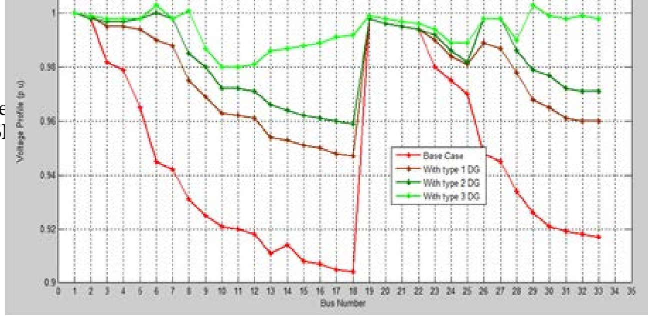


Figure 11: Voltage profile of 33 buses network after placement of DG type 3

8.0 CONCLUSION

The application of DG will reduce CO2 emission, and global warming due to the fact that most the primary energy sources of DG are renewable. In the analysis, it is observed that total network losses will be more reduced by installing DG type 1 in comparison with DG type 2 in the network. Therefore, by installing a DG that is able to generate active and reactive power in the network will further reduce losses and improve the economic criterion. Finally, it can be seen from results that optimal size and location of DG will reduce the power loss and improve the voltage profile compare to the case without DG, which in turn reduce the capital investment on installation and operation.

9.0 APPENDIX

Table AI. Load data for 33-bus distribution system

Bus No.	P_L (KW)	Q_2 (KVAr)	Bus No	P_L (KW)	Q_2 (KVAr)
2	100	60	18	90	40
3	90	40	19	90	40
4	120	80	20	90	40
5	60	30	21	90	40
6	60	20	22	90	40
7	200	100	23	90	40
8	200	100	24	420	200
9	60	20	25	420	200
10	60	20	26	60	25
11	45	30	27	60	25
12	60	35	28	60	20
13	60	35	29	120	70
14	120	80	30	200	100
15	60	10	31	150	70
16	60	20	32	210	100
17	60	20	33	60	40

TABLE AII. Branch DATA FOR 33-BUS DISTRIBUTION SYSTEM.

Branch Number	Sending End bus	Receiving End bus	R (Ω)	X (Ω)
1	1	2	0.0922	0.0470
2	2	3	0.4930	0.2512
3	3	4	0.3661	0.1864
4	4	5	0.3811	0.1941
5	5	6	0.8190	0.7070
6	6	7	0.1872	0.6188
7	7	8	0.7115	0.2351
8	8	9	1.0299	0.7400
9	9	10	1.0440	0.7400
10	10	11	0.1967	0.0651
11	11	12	0.3744	0.1298
12	12	13	1.4680	1.1549
13	13	14	0.5416	0.7129
14	14	15	0.5909	0.5260
15	15	16	0.7462	0.5449
16	16	17	1.2889	1.7210
17	17	18	0.7320	0.5739
18	2	19	0.1640	0.1565
19	19	20	1.5042	1.3555
20	20	21	0.4095	0.4784
21	21	22	0.7089	0.9373
22	3	23	0.4512	0.3084
23	23	24	0.8980	0.7091
24	24	25	0.8950	0.7071
25	6	26	0.2031	0.1034
26	26	27	0.2842	0.1447
27	27	28	1.0589	0.9338
28	28	29	0.8043	0.7006
29	29	30	0.5074	0.2585
30	30	31	0.9745	0.9629
31	31	32	0.3105	0.3619
32	32	33	0.3411	0.5302
34	8	21	2.0000	2.0000
35	9	15	2.0000	2.0000
36	12	22	2.0000	2.0000
37	18	33	0.5000	0.5000
33	25	29	0.5000	0.5000

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