NEW OPTIMIZATION METHOD OF DISPERSED GENERATION IN ELECTRICAL DISTRIBUTION SYSTEMS FOR REDUCING LOSSES

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Abstract: *Dispersed Generation (DG) is a promising solution to many power system problems such as voltage regulation and power loss. This paper proposes a heuristic two-step method to optimize the location and size of DG for reducing active power losses and, therefore, improve the voltage profile in radial distribution networks. In addition to a DG placed at the system load gravity center, this method consists in assigning a DG to each lateral of the network. After having determined the central DG placement, the location and size of each lateral DG are predetermined in the first step. The results are then refined in the second step. This method is tested for 33-bus system for 100% DG penetration. The results obtained are compared with those of other methods found in the literature.*

Key words: *Optimal location, optimal size, dispersed generation (DG), radial distribution networks, reducing losses.*

1. Introduction

The deregulation of electricity markets, the growing interest to the environment and technological developments of the means of small production have enormously contributed to the development of a new category of energy generation called dispersed generation or distributed generation (DG). It is a production of electrical energy on a small scale generally connected to the distribution network, close to consumers [1], [2]. It can be based on renewable energy (wind, solar, hydro), gas or fossil fuels. Its size can vary from a few kilowatts to more than a few megawatts [3]. It has gained more attention because of its rapid growth and environmental concerns. It provides a good immediate solution to the growing energy demand due to its short construction timelines and its low installation costs. It allows relieving the transmission and distribution capacity and, therefore, deferring the investments. It is invoked to play an important role and to become one of the areas research the most attractive in studies of energy systems.

The presence of DG in distribution networks could improve the system efficiency, reliability, safety and quality of service. However, it could have a critical impact on the energy losses, the voltage profile, the supply quality, the short-circuit level and interact with the functioning of on-load tap-changer and protection coordination [4-5]. Their optimal location and sizing is a problem of great importance in the electrical systems planning. Several optimization techniques have been applied to determine the DG location and sizing such as genetic algorithms [6], tabu search [7], particle swarm optimization [8-10], heuristic methods [11], load flow algorithm [12] and analytical approaches [13-14]. In [15], a state of the art was presented on models and optimization methods used for placement and sizing of DG in distribution networks. Different objectives such as the active losses minimization [16-18], improvement of the voltage profile [19-20], improvement of the reliability [21-22], investment costs minimization [23-24] and environmental impact reduction [25] were targeted using a single or multiple objective formulation [26-27].

Our work consists to propose a heuristic method for optimize the number, location and size of the DG for reducing active losses in electrical distribution networks and, therefore, improve the voltage profile. This work is organized as follows. The DG optimization problem formulation, to reduce active losses in distribution networks, is presented in section 2. The method of solving the problem is explained in section 3. The results are presented, discussed and compared in section 4. Finally, conclusions are made in section 5.

2. Problem Formulation

The location and size of the distributed energy generation in a radial distribution system are optimized by minimizing the active system losses as follow:

minimize

$$P_L = \sum_{i=1}^{n} P_i \tag{1}$$

subject to constraints:

$$P_i = P_{GI} - P_{Di} = V_i \sum_{i=1}^{n} Y_{ik} V_k \cos(\delta_k - \delta_i + \gamma_{ik})$$
$$Q_i = Q_{GI} - Q_{Di} = -V_i \sum_{i=1}^{n} Y_{ik} V_k \sin(\delta_k - \delta_i + \gamma_{ik}) \tag{2}$$

$$V_{min} \leq V_i \leq V_{max} \quad \text{for } i = 1, \ldots, n \tag{3}$$

$$I_k \leq I_{k,max} \quad \text{for } k = 1, \ldots, m \tag{4}$$

where:
P_L is the total active losses in the network,
n is the total number of nodes,
P_i, Q_i are the active and reactive injections at node i,
P_{Gi}, P_{Di} are respectively the generated and consumed active powers at node i,
Q_{Gi}, Q_{Di} are respectively the generated and consumed reactive powers at node i,
V_i, δ_i are the amplitude and phase of the voltage at node i,
Y_{ik}, γ_{ik} are the amplitude and phase of the branch admittance between nodes i and k,
V_{min}, V_{max} are respectively the lower and upper node voltage limits,
I_k is the current in the branch k,
$I_{k,max}$ is the upper current limit in the branch k,
m is the total number of branches.

Equation (1) is the objective function, Equation (2), equality type constraints, represents the load flow equations. Equations (3) and (4) represent respectively the inequality type constraints of voltage and current.

3. Explanation of the method

Our method is based on the idea that the global optimum for the minimization of active losses can be obtained theoretically when at each node of the system is connected a DG having a power equal to the load of this node. A practical solution, which closer to the global optimum, consists to install an optimal number of DG at places well distributed of the system. An efficient solution can be used by sharing the total system load in load groups and affect a DG to each group. For example, at each lateral of the network, we assign a group of loads and a DG generally placed at the gravity center of this load group. Figure 1 shows such a load partition.

Indeed, our proposed method is based on this partition. In addition to a central DG located in the system load gravity center, this method consists to associate to each lateral of the system a load group and a DG. Based on an iterative load flow algorithm, the proposed method is implemented in two steps. In the first step, we predetermine the location and size of these DGs based on the heuristic techniques. In the second step, a refinement operation is applied to further reduce the active losses and determine definitively the optimal locations and sizes of DG.

A. First step

In this first step, we start by performing a first load flow calculation without DG for classify the network laterals in a decreasing order. The lateral which has a larger voltage drop is ranked the first, and so on. Then, we determine the location of the central DG which represents the gravity center of the total system load. This central location, generally located on the main feeder at a few nodes from the source can be determined by an iterative load flow calculation. At each iteration, we choose a reference node other than that of the source. The reference node for which losses are more minimal is considered as central location. The initial size of this central DG is taken equal to the entire system load.

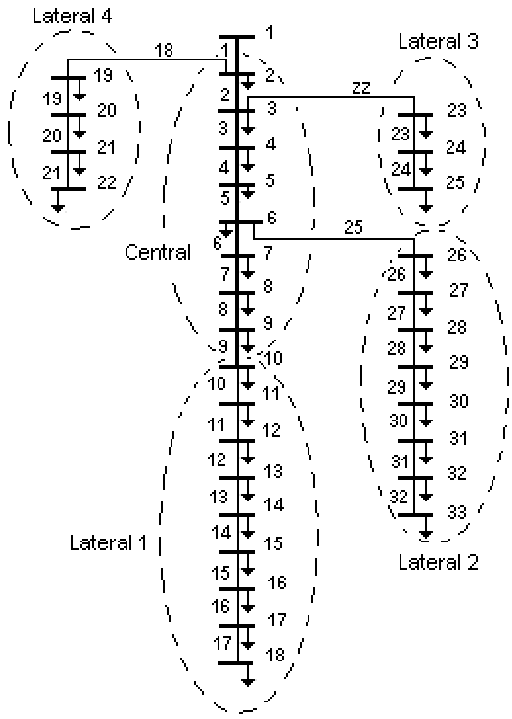

Fig 1. Partition of the total load into load groups

In order to determine the locations and sizes of DG associated to the laterals, we connect, by a very small impedance line, the end of each lateral to the central location, as shown the figure 2. Then, we do a new load flow calculation by taking the central location as reference node. For each loop thus formed, we determine a minimum voltage node. It is in these nodes of minimum voltage that we must place initially the lateral DGs for reduce the losses and there fore improve the tension profile. The size of each lateral DG is calculated by summing the node loads since the node to which is connected the DG until the end of the lateral. The initial size of the central DG must be adjusted by subtracting from it those of lateral DG.

Finally, we delete the loopback lines and we place the DGs at their predetermined locations then we perform a load flow calculation, where the source node is taken as reference node, for calculating the active losses at this first step.

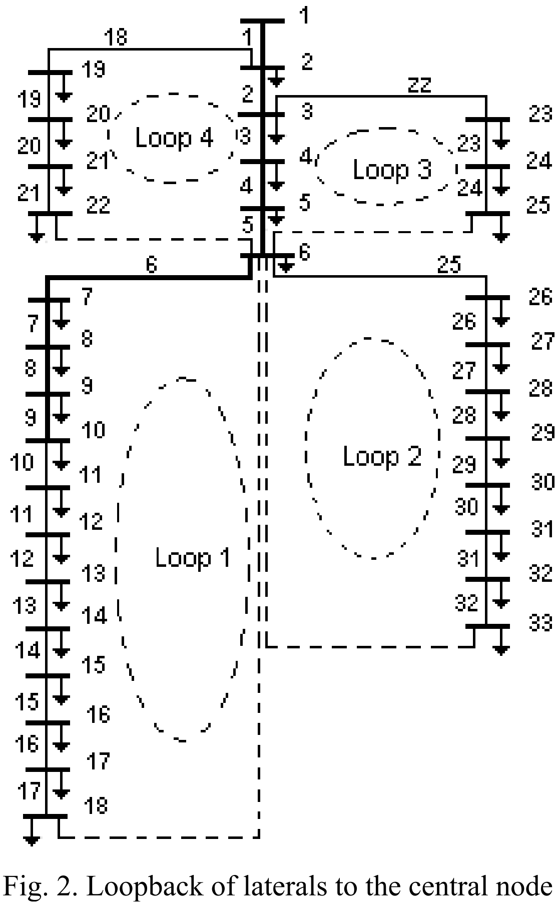

Fig. 2. Loopback of laterals to the central node

B. Second step

In the second step, we proceed to a first refinement technique which consists in performing a charge transfer from the central DG towards the first lateral DG. This transfer is effected load by load. At each transfer operation, we calculate the active losses. The charge transfer process is stopped when no reduction in losses is reported. This iterative process of load transfer is repeated for all the lateral DGs following the decreasing order of the laterals. It allows determining definitively the optimal DG sizes.

A second refinement technique applied consists in displacing from one node, to the right or left, each lateral DG and check whether this reduces the active losses. This displacement allows determining definitively the locations of the lateral DGs. The final losses, calculated after these two refinement processes, are considered as optimal very close to the global optimum.

In reality, this optimization procedure is used for 100% of DG penetration. For a lower rate, we must take this into account in the initial dimensioning of the central DG. For a rate relatively small, it may be that, during the charge transfer, the size of the central DG becomes negative. In this case, we must get rid of the central DG and stop the charge transfer process.

The algorithm of the proposed method includes the following points:

1. introduce the necessary network data including the DG penetration rate,
2. evaluate a load flow calculation and classify the network laterals according to the voltage drop, the lateral which has the higher voltage drop is ranked the first,
3. assign to each network lateral a DG, said lateral,
4. by an iterative load flow calculation, determine the location of the central DG, as mentioned previously,
5. loop the ends of the system laterals to the central DG location,
6. perform a load flow calculation by taking the central location as reference node,
7. for each loop thus formed, determine a node of minimum voltage,
8. take the initial size of the central DG equal to the total system load multiplied by the DG penetration rate,
9. calculate the size of each lateral DG on the basis of the node of minimum voltage as mentioned previously,
10. adjust the initial size of the central DG by subtracting from it those of the lateral DGs,
11. remove the loopbacks made in point 5, then connect the central DG to its location and the lateral DGs to the nodes with minimum voltage determined in point 7,
12. by taking le source node as reference, run a load flow calculation to compute the active losses at the end of the first step,
13. proceed to the load transfer from the central DG toward the first lateral DG until there is no reduction in active losses,
14. repeat this load transfer process for the all lateral DGs, according to the descending order done at the point 2
15. if the size of the central DG becomes negative, stop the load transfer process and get rid of the central DG,
16. move the location of each lateral DG from one node, to the right or the left, for a possible reduction of active losses,
17. run a last load flow calculation to evaluate the final active losses,
18. stop.

4. Results and Discussions

Our proposed method is tested for the 33-bus, 12.66 kV system given in [28], very often used in the literature. It is a radial distribution network having a total load of 3715 kW and 2300 kVAr. The active losses, without DG, are equal to 202,68kW. The electrical parameters of lines and loads are given in appendix A. Its single-line diagram is shown in the figure 1.

At the beginning of the first step, we run a first load flow calculation to compute the node voltages without DG and classify the system laterals according the highest voltage drop. Then, we determine the node at which will be connected the central DG. According to the test network structure, this node can not be outside the nodes 2, 3, 4 ... 9. It can be obtained by an iterative load flow calculation. At each iteration, we choose one of these nodes as reference node. The reference node that corresponds to the most minimal losses is chosen as the central location. Indeed, this node, located on the main feeder not far from the source, is number 6. It is determined during a few iterations only. The initial size of the central DG is taken equal to the total active load of the system, that is to say, for a DG penetration rate of 100%.

The central node being determined, we link the end of each lateral to this central node number 6 by a line of low impedance, as indicated in figure 2. By taking node 6 as reference node, we perform a load flow calculation for determining, for each loop formed, a node of minimum voltage at which will be connected initially a lateral DG. The size of the first lateral DG, initially placed to node 13 of minimum voltage, is initially calculated from the sum of the loads connected to the nodes numbered from 13 to 18. The size of the central DG is therefore adjusted by subtracting from it this sum of loads. The same procedure of sizing is applied to the rest of the lateral DG. The results of this first step are summarized in Table 1.

Table 1
Locations and sizes determined during the first step for 100% DG penetration

Laterals	Location nodes	Sizes (MW)
Lateral 1	13	0.450
Lateral 2	30	0.620
Lateral 3	23	0.930
Lateral 4	19	0.360
Central	6	1.355

Finally, we remove the loopbacks and we place the DG in its predetermined locations then we execute a load flow calculation to calculate the active losses in this first step. They are found equal to 72,737 kW.

To further reduce the active losses, we proceed to the second step said of refinement. First, we proceed to the load transfer from the central DG towards the other lateral DGs. We begin by transferring the load of the node 12 from the central DG to the first lateral DG. Then, by a load flow calculation, we calculate the active losses to know if a reduction of active losses can take place. This load transfer technique is applied successively to the loads of the nodes 11 and 10. This load transfer process is repeated for the rest of the lateral DG according to their descending ranking.

Finally, we proceed to the second refinement technique that allows determining definitively the lateral DG locations. It consists to displace the lateral DG from one node, to the right or left, for a possible decrease in the active losses. Indeed, the application of this technique allows placing definitively the first lateral DG to the node 14. This technique of to move the DG is applied to the rest of the lateral DGs. The final locations and sizes of the DG are shown in Table 2. The active losses are reduced to 65,334 kW at the end of the second step. As a consequence, the voltage profile is much improved as shown in the figure 3.

Table 2
Final locations and sizes for 100% DG penetration

Laterals	Location nodes	Sizes (MW)
Lateral 1	14	0.615
Lateral 2	31	0.800
Lateral 3	24	1.020
Lateral 4	20	0.460
Central	6	0.820

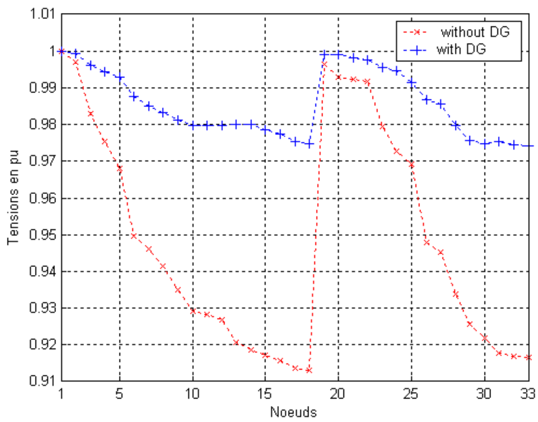

Fig. 3. Voltage profile with and without DG

Our proposed method is compared to the method presented in [27]. The results of this comparison are indicated in Table 3 for 83.13% DG penetration. This latter is calculated from the total DG size predicted by the method of reference [27]. It must be noted here that the DG size of the lateral 4 is found equal only to the load of the node 22. Practically it is not feasible to connect a DG so small. Our proposed method leads to results better than those found in [27].

Table 3
Comparison Results for 83.13% of DG penetration

Method in [27]			Proposed method		
Location nodes	Sizes (MW)	Losses (kW)	Location nodes	Sizes (MW)	Losses (kW)
15	0.5757	66.589	14	0.6150	66.243
32	0.6538		31	0.7400	
25	0.7824		24	0.9300	
6	1.0765		6	0.8033	
Total size	3.0884		Total size	3.0883	

5. Conclusions

An effective heuristic method to optimize the DG location and size in the electrical distribution networks is presented in this work. The theoretical 33-bus network is used as a test system to confirm the effectiveness of the proposed method. The results showed that the optimal DG location and size are better than that found in the literature. This allows us to qualify our proposed method as the most effective. It can be used as a tool for the DG planning in the electrical distribution networks.

Appendix A. Data of the 33-bus distribution system

line no	Sending bus	Receiving bus	R (Ω)	X (Ω)	P_D (kW)	Q_D (kvar)
1	0	1	0.0922	0.0470	100	60
2	1	2	0.4930	0.2511	90	40
3	2	3	0.3660	0.1864	120	80
4	3	4	0.3811	0.1941	60	30
5	4	5	0.8190	0.7070	60	20
6	5	6	0.1872	0.6188	200	100
7	6	7	0.7114	0.2351	200	100
8	7	8	1.0300	0.7400	60	20
9	8	9	1.0440	0.7400	60	20
10	9	10	0.1966	0.0650	45	30
11	10	11	0.3744	0.1238	60	35
12	11	12	1.4680	1.1550	60	35
13	12	13	0.5416	0.7129	120	80
14	13	14	0.5910	0.5260	60	10
15	14	15	0.7463	0.5450	60	20
16	15	16	1.2890	1.7210	60	20
17	16	17	0.7320	0.5740	90	40
18	1	18	0.1640	0.1565	90	40
19	18	19	1.5042	1.3554	90	40
20	19	20	0.4095	0.4784	90	40
21	20	21	0.7089	0.9373	90	40
22	2	22	0.4512	0.3083	90	50
23	22	23	0.8980	0.7091	420	200
24	23	24	0.8960	0.7011	420	200
25	5	25	0.2030	0.1034	60	25
26	25	26	0.2842	0.1447	60	25
27	26	27	1.0590	0.9337	60	20
28	27	28	0.8042	0.7006	120	70
29	28	29	0.5075	0.2585	200	600
30	29	30	0.9744	0.9630	150	70
31	30	31	0.3105	0.3619	210	100
32	31	32	0.3410	0.5302	60	40

Allowable voltage drop: ± 5 %.
Line transmission capacity: 400 A for lines 1 to 9, 200 A for the rest.

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