Selection of DG Units and Location in Radial Distribution Networks

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Abstract – **This paper presents a methodology of optimal power selection and procedure for finding convenient location of distributed generations (DG) in the aim of total real power loss reduction in the radial distribution networks. This methodology is based on exact formula for real power losses in distribution network. Impact of DG size and location to real power losses has been investigated. Calculation results are illustrated on standard IEEE 32 node MV distribution test network.**

Keywords – **Distributed generation, Radial distribution network, Power losses**

I. INTRODUCTION

The share of distribution generation in power systems has been slowly increasing in recent years. There is an initiative to promote DG and it means that number of the generators will be quickly increasing, especially in distribution systems. Definition of distribution production assumes different shapes on the markets in different countries. Usually it is defined as production plant serving consumer on the spot or support distribution network. Distribution generator is electric energy source connected directly to distribution network. DG can be considered as one option for energetic problem mitigation with who power system is confronted and to cope with continually increasing of electric energy demand.

The biggest interest is to arrange DG locations in optimal way to diminish power losses of distribution systems and in the same way to improve voltage profile. So, DG must be placed on convenient locations and have suitable size. Unadequate selection of DG location and size can lead to bigger losses than in a case without DG. Due to it, it is necessary to develop the tools for investigation location and size of DGs. There are many accesses for determination of DG location and size in intention of loss minimisation as: classical method [1], genetic algorithm [2], fuzzy genetic algorithm [3], tabu search [4] and analytic accesses [5-9].

There are two accesses. The first one determinates optimal DG location and size supposing that DG can be installed in every node without any constraints. According the second, analytic principle, one optimal size and location is searched on the base of current flows for supposed load distribution along the line. Often so called "Golden Rule" or "2/3 rule" is used when DG is installed with size equal to 2/3 of total consumption power at the distance of approximately 2/3 of line length. This rule is simple but can be applied only at radial lines with equal distributed load alongside the line. Paper (9) gives analytical expressions for optimal size and location for different load distributions alongside the line.

In [6], DG location and size is determined on the base of sensitivity factors. Although, it is shown that sensitivity factors are not reliable indices of DG location, especially at radial distribution networks with bigger DG units.

This paper shows the methodology where optimal DG size is determined on the base of simple analytical expressions, and then optimal DG location is selected by loss diminishing search. Section II gives survey of the methodology of optimal DG size calculation. Section III shows numerical results on IEEE the 33-node test distribution network, remarks and discussion also. At the end, the conclusions are summarized in section IV.

II. METHODOLOGY

Total active power losses, ΔP, in distribution network with n branches are obtained as a sum of losses in some branches,

$$\Delta P = 3\sum_{i=1}^{n} R_i J_i^2 , \tag{1}$$

where R_i is resistance of branch i and J_i is the magnitude current flow in branch i.

The branch current can be obtained from the load flow solution. The branch current (J_i) has two components, active component (J_{ai}) and reactive component (J_{ri}). The losses associated with the active and reactive components of branch currents can be written as

$$\Delta P = \Delta P_a + \Delta P_r . \tag{2}$$

$$\Delta P = 3\sum_{i=1}^{n} R_i J_{ai}^2 + 3\sum_{i=1}^{n} R_i J_{ri}^2 . \tag{3}$$

For a given configuration of a single source radial distribution network, the losses ΔP_a associated with the active component of branch current can not be minimized because all the active power must be supplied by the source at the root bus. However by placing DGs, the active components of branch currents are compensated and losses due to active

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components of branch currents are reduced. Simultaneously, there is significant change of reactive power losses.

In this work, main interest is active power losses ΔP_a in distribution network. DG influence to reactive power losses and voltages is neglected. It should find optimal DG size and location to obtain biggest decreasing of losses.

The methodology of selection of DG size and location can be explained on the feeder sample with n branches, shown on Fig. 1. Let DG is connected at bus k with current I_{DG} injected in the network.

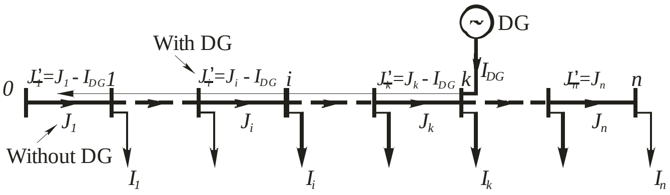

Fig. 1. Radial feeder with DG connected at bus k

As it is shown on Fig. 1, DG connection to system results with current reduction flowing from root substation to the node of DG connection, but there is no influence to branch currents from node k to terminal one n.

The currents of some feeder branches are

$$J_i' = \begin{cases} J_i - I_{DG} & i \le k \\ J_i & i > k \end{cases}. \tag{4}$$

Let DG inject active power and active component of current only I_{DG}. Then, active power losses, $\Delta P_a'$, depending on active components flows of branch currents become

$$\Delta P_a' = 3\sum_{i=1}^{k} R_i (J_{ai} - I_{DG})^2 + 3\sum_{i=k+1}^{n} R_i J_{ai}^2 . \tag{5}$$

Diminishing (saving) of active power losses is

$$S = \Delta P_a - \Delta P_a' = 3\sum_{i=1}^{k} R_i J_{ai}^2 - 3\sum_{i=1}^{k} R_i (J_{ai} - I_{DG})^2 . \tag{6}$$

Maximal saving is obtained when derivation of (6) by I_{DG} is equal to zero,

$$\frac{dS}{dI_{DG}} = \Delta P_a - \Delta P_a' = 2 \cdot 3\sum_{i=1}^{k} R_i (J_{ai} - I_{DG}) = 0 . \tag{7}$$

From Eq. (7) follows that maximal saving is obtained when DG current is

$$I_{DG} = \frac{\sum_{i=1}^{k} R_i J_{ai}}{\sum_{i=1}^{k} R_i} . \tag{8}$$

Corresponding active power of three-phase DG will be

$$P_{DG} = \sqrt{3} V_k I_{DG} , \tag{9}$$

where V_k is voltage in the node k. Optimal DG power in each node is determined on the base of Eq. (9). The change of DG active power losses in any node is calculated by Eq. (6). DG with biggest loss changing is "candidate" for a location for one DG placement.

Calculation procedure for determination of DG size and location is carrying out according following algorithm.

1. Load flow calculation for basic case (without DG).
2. Optimal current I_{DG} and power P_{DG} calculation of DG by using Eqs. (8) and (9).
3. Calculation of total active power losses by means Eq. (5) for every node by putting DG of optimal power at this node.
4. Node selection for which we have minimal active power losses (maximal saving) after DG connection at optimal location.
5. To change total active power of the node selected for DG placement for the amount of DG optimal power in that node.
6. To carry out analysis of power/current flows of distribution network with switched on DG.
7. To check is the voltage values are inside allowed borders.
8. If node voltage values ware not inside allowed borders then DG should be omitted from given node and procedure would return to the step 4.

If there was more DGs, next "node candidate" for DG placement, would be determined so that process would be repeated assuming that the first DG is put at optimal place and operate with optimal power. Placement of next DG would be justified if significant further loss diminishing achieved. On that way, all locations candidates for DG placement are established.

As DGs are added one by one, the powers obtained by each DG placement are optimal locally, so they are not global optimal solution. Global optimal solution was obtained if more DGs would be put in the system simultaneously [4].

III. SIMULATION RESULTS AND ANALYSIS

The methodology of DG optimal size and location calculation is applied on test network of rated voltage U_n=12.66kV containing 33 nodes and 32 branches, shown on Fig. 2 [9]. This is radial distribution network with total consumption power of $3715\,\mathrm{kW}$ and $2300\,\mathrm{kVAr}$. Load flow and voltage calculation is made according power summation method. After iterative procedure finishing, power and current flows are obtained, and current components along network branches also. On the base of them power losses in each branch and total network losses are calculated.

At root node voltage $U_0 = 12.66\mathrm{kV}$ and at basis loads, total active power losses are $\Delta P = 202.677\,\mathrm{kW}$, power losses depending on active component of current are $\Delta P_a = 135.527\,\mathrm{kW}$ and power losses depending on reactive component of current are $\Delta P_r = 67.150\,\mathrm{kW}$.

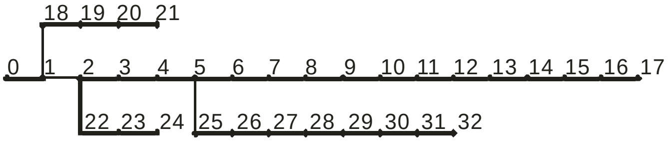

Fig. 2. Single-line diagram of the test network

On the base of established currents along network branches, optimal DG currents and powers are calculated according Eqs. (8) and (9), respectively. Optimal DG powers are shown on Fig. 3.

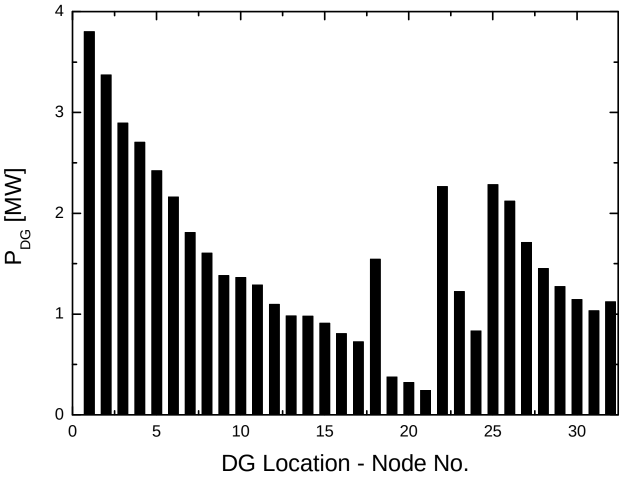

Fig. 3. Optimal DG powers for every nodes

Maximal loss diminishing appears when DG of power $P_{DG} = 2.4218\,\text{MW}$ is installed at the node 5. By DG integration in distribution network all branch currents are reduced from root node to the node number 5. Fig. 4 shows active current components along the branches before and after DG installing. Active current component of supply (the first) branch is diminishing from 178.6348A to 63.6279A. Simultaneously, total current is decreasing from 210.3644A to 125.6622A (reduction is 59.97%).

By current reduction, active power losses along branches are reduced, what is shown on Fig. 5. By installing DG total active power losses fall to $\Delta P^{'} = 104.2926\,\text{kW}$.

DG installing results better voltage conditions. Voltage profile at network nodes with and without DG is shown on Fig. 6. Voltages of outskirts nodes 17 and 32 are increasing for 3.922% and 3.896%, respectively.

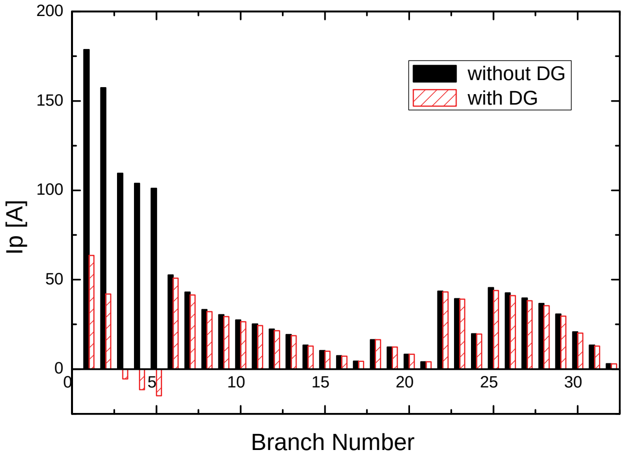

Fig. 4. Active components of branch currents with and without DG

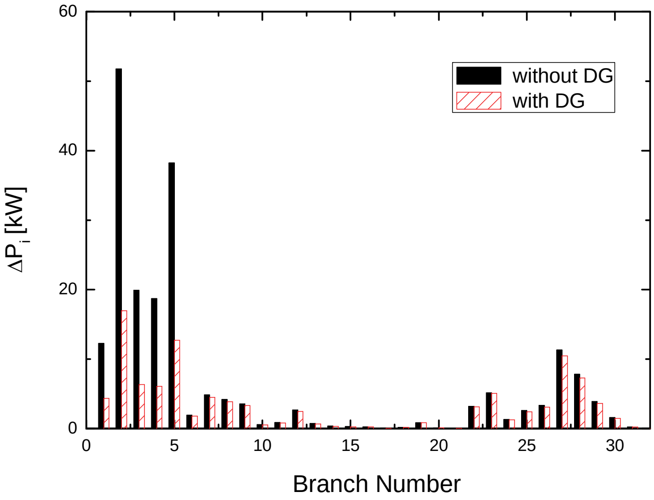

Fig. 5. Active power losses of each branch with and without DG

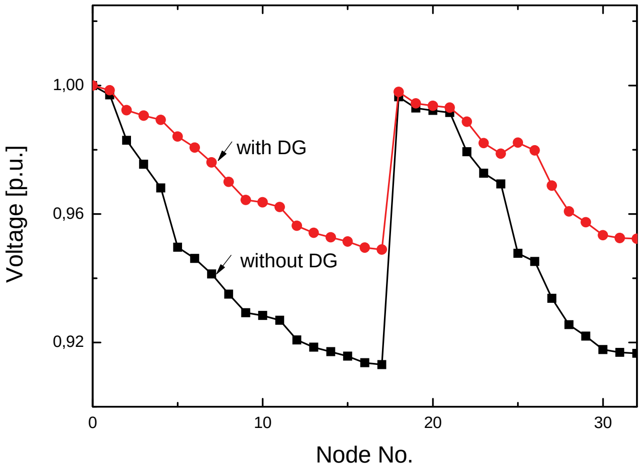

Fig. 6. Voltage profile of the test network with and without DG at the node number 5

Often the size of DG is limited. If DG is mobile one, logic question arises where to connect DG to achieve minimal network losses. Investigations are carried out for four different powers of DGs (0,5MW, 1MW, 2MW and 3MW). Active power losses of the test network for four different sizes of DG are shown on Fig. 7.

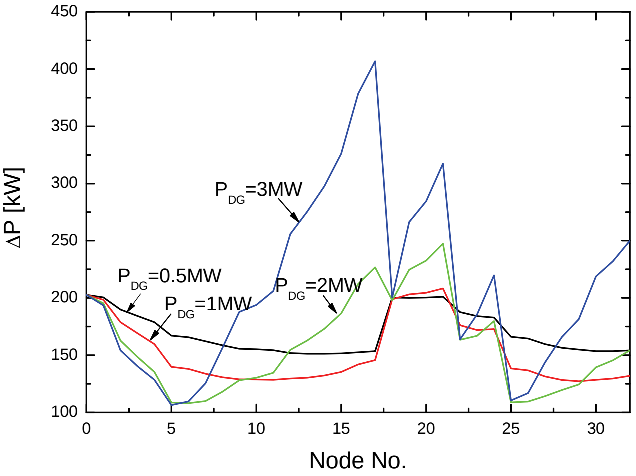

Fig. 7. Active power losses for different sizes of DG at single nodes

Obviously, contribution of DG to losses diminishing depends very much on the place of connection (DG location). So, efficiency of DG of the least power grows if it is connected further from root node.

DG of small power is the best to connect to the nodes 17 or 32, to most far nodes. DGs of powers 2MW and 3MW should be connected to the node 5 or 6. DG connection of power 3MW at the nodes 11, 12, 13, 14, 15, 16, 17, 19, 20, 21, 24, 30, 31 and 32 is increasing losses. Negative effect is bigger if DG is closer to terminal node. From this we can conclude that loss sensitivity to active consumption power at the node is not reliable index for selection of DG optimal location.

IV. CONCLUSION

This work shows the methodology of finding optimal DG size and location for maximal reduction of active power losses in radial distribution networks. The method is simple, fast and gives results of sufficient exactness. DG location is established by search of results of loss diminishing for calculated optimal powers for every node. Although this paper analysis the case of single DG putting, this procedure can be used for calculation DG location and size in more nodes. By installation of DG at optimal location, total power losses in the system are reduced drastically, and voltage profile is improved also.

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