

A Novel Method for Optimal Distributed Generator Placement in Radial Distribution Systems

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ABSTRACT

Optimal placement of distributed generators is essential, as inappropriate placement may increase the system losses. This article proposes a novel methodology for finding the optimal size and location for installation of Distributed Generators (DGs) so as to minimize total power losses in radial distribution systems. Distribution load flow is used to find the power loss in the system. The Proposed methodology is tested with 69-node radial distribution system with single and multiple DGs and the efficacy is compared with the Acharya's method and classical grid search algorithm. Effect of optimal DGs placement on system voltage profile and branch power losses are also computed and reported.

Key Words: Distributed generators, load flow, optimal locations, optimal sizes, power loss reduction, radial distribution system.

INTRODUCTION

The planning of the electric system with the presence of Distributed Generator (DG) requires the definition of several factors, such as: the best technology to be used, the number and the capacity of the units, the best location, the type of network connection, etc. The impact of DG in system operating characteristics, such as electric losses, voltage profile, stability and reliability needs to be evaluated. The problem of DG allo-

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cation and sizing is of great importance. The installation of DG units at non-optimal places can result in an increase in system losses, implying in an increase in costs and, therefore, having an undesired effect.

Distributed or dispersed generator may be defined as a generating resource, other than central generating station, that is placed close to load being served, usually at customer site. It may be connected to the supply side or demand side of meter. It can be renewable sources based micro hydro, wind turbines, photovoltaic, etc or fossil fuel based fuel cells, reciprocating engines, micro turbines, etc. In term of size, DG may range from few kilowatts to over 100 megawatts [1].

The share of DGs in power system is increasing world wide and their contribution in the future power system is expected to be even more [2], [11]-[13]. Energy policies worldwide are encouraging the installation of DGs in both transmission and distribution networks along with large scale power generating plants. The general belief is that the future of the power generation will be DGs. But the fact is that the distribution systems were not planned to support the installation of active power generating units in them. DGs come with opportunities as well as challenges.

A near optimal placement technique to reduce the system loss has been presented in [3] using .B. loss coefficient. The buses are ranked according to their loss sensitivity and size of DG is found in stepwise manner. This method is basically concerned with finding the optimal location of DG and loss sensitivity method always does not give the accurate result. Genetic Algorithm (GA) based distributed generator placement techniques are used to reduce overall power losses in distribution system are presented in [4-7] but the problems with GA are that it is computationally intensive and suffers from excessive convergence time and premature convergence. Hereford ranch algorithm is used to optimally locate the DG to reduce the system overall real power loss under the constraint of the total injection of installed dispersed generation in [8]. Similar to the GA based methods. This method is also computationally demanding though it addresses the issue of premature convergence and has the ability to search for a better optimal solution. In [9], the optimal location to place a DG, with unity power factor, in a radial or looped system is found while minimizing the loss. This technique is basically concerned with finding the optimal location not the optimal size.

In [10] the optimal size and location of DG is calculated based on exact loss formula and compared with successive load flows and loss

sensitivity methods. The method is computationally less demanding for radial and networked systems, however, it requires the calculation of the bus impedance matrix, Z_{bus} , the inverse of the bus admittance matrix, Y_{bus} . It should be noted that due to the size, complexity and specific characteristics of distribution networks, the method could not be directly applied to distribution systems. It fails to meet the requirements in robustness aspects in the distribution system environments [14].

In this article, a novel method to identify the optimum location for DG placement and a simple expression to calculate optimum size is proposed. The methodology is computationally very demanding when comparing with Acharya's method [10] and Grid search algorithm [18]. The DG is considered to be located in the Radial Distribution System (RDS). The objective of DG placement is to reduce the system power. See a diagram of the studied RDS in Figure 4. The cost of DG associated benefits has been considered after solving the location and sizing problem. The sizing and placement of DG is based on single instantaneous peak, where the losses are maximized by compared existing methods and also extended to multiple DGs placement. The proposed methodology has less computation time compared with the existing methods.

PROBLEM FORMULATION

The total active power loss for an RDS with branches is given by

$$TLP = \sum_{i=1}^b I_i^2 R_i \quad (1)$$

where I_i and R_i are the current magnitude and resistance, respectively, of branch i .

The branch currents can be obtained from the load flow technique [15]. This current has two components; active (I_{ai}) and reactive (I_{ri}). Thus, the total real power loss of the system can be written as

$$TLP = \sum_{i=1}^b I_a^2 R_i + \sum_{i=1}^b I_r^2 R_i \quad (2)$$

$$\therefore TLP = TLP_a + TLP_r \quad (3)$$

Note that for a given configuration of a single source radial network, the loss TLP_a associated with the total active component of branch currents can be minimized by supplying part of active power demands locally with distributed generators. However, the loss TLP_r associated with the total reactive component of branch currents can be minimized by supplying part of the reactive power demands locally with capacitors.

In the proposed method, the idea is to place a unity power factor DG with such a size and location so that the system loss reduction is maximized—i.e. the grid's transmission and distribution losses are minimized. The governing equations can be derived as follows:

When a unity power factor DG is placed at node k , the current I_{dgk} flows towards the substation and the current flowing to the respective branches reduces, whereas, the remaining branches there is no change in the branch currents than, the total real power loss of the system is obtained from Eqn. (3) as

$$TLP = \sum_{i=1}^k (I_{ai} + I_{dgk})^2 R_i + \sum_{i=k+1}^{br} I_{ai}^2 R_i + \sum_{i=1}^{br} I_{ri}^2 R_i \quad (4)$$

Subtracting Eqn. (4) from Eqn. (2), the loss reduction ΔTLP_k can be written as:

$$\Delta TLP_k = -2I_{dgk} \sum_{i=1}^k I_{ai} R_i - I_{dgk}^2 \sum_{i=1}^k R_i \quad (5)$$

Assuming that there is no significant change in the node voltage after setting the DG, the DG current I_{dgk} that provides the maximum loss saving can be obtained from

$$\frac{\partial(\Delta TLP_k)}{\partial I_{dgk}} = -2 \left(\sum_{i=1}^k I_{ai} R_i + I_{dgk} \sum_{i=1}^k R_i \right) = 0 \quad (6)$$

Thus the DG current for maximum loss saving is

$$I_{dgk} = - \frac{\sum_{i=1}^k I_{ai} R_i}{\sum_{i=1}^k R_i} \quad (7)$$

The size of DG at node 'k', $P_{dgk} = I_{dgk} V_k$ (8)

where V_k is the voltage magnitude of the DG node k

The above process can be repeated for all nodes except the source node to get the highest possible loss saving for a singly located DG. When the candidate node is identified and placed, the above technique can also be used to identify the next and subsequent nodes to be evaluated for loss reduction. Such evaluations will provide the locations where the DGs are to be placed.

For evaluation, the net cost saving is defined in the form of

$$S = K_{TLP} TLP + K_{dgk} P_{dgk} \quad (9)$$

where K_{TLP} is the annual cost per kilowatt loss in \$/kW,
 K_{dgk} is the annual cost in \$/kW for the DG placed at node k

In this article, the K_{TLP} value is taken as 100 \$/kW and K_{dgk} as 0.5 \$/kW, where the costs are hypothetical which are taken from [16]. By placing the optimal DG at optimal location k, the net cost saving is

$$\Delta S_k = K_{TLP} \Delta TLP_k + K_{dgk} P_{dgk} \quad (10)$$

PROPOSED METHOD FLOWCHART

The computational steps involved in finding the optimal DGs size and locations to minimize the total real power loss of radial distribution system is summarized in Figure 1.

SIMULATION RESULTS AND ANALYSIS

Single DG Placement

In order to evaluate the proposed algorithm, one test system, taken from the literature, is used. Accordingly, optimum size and place of DGs for 69-bus distribution test system [17] are determined with three methods:

- The method proposed here
- Acharya's method [10], and
- The classical grid search algorithm.

The total real and reactive power loads at nominal voltage are 3.7918 MW and 2.6834 MVAR respectively. The classical grid search algorithm is employed with the power flow program MATPOWER [18] to validate the results. The classical grid search algorithm is too costly because of computation time, that takes hours even days depending upon size of the system and power steps. By using variable step size, successive load flows as also known sequential load flows could be employed instead of grid search algorithm. In this case, computation time will reduce significantly.

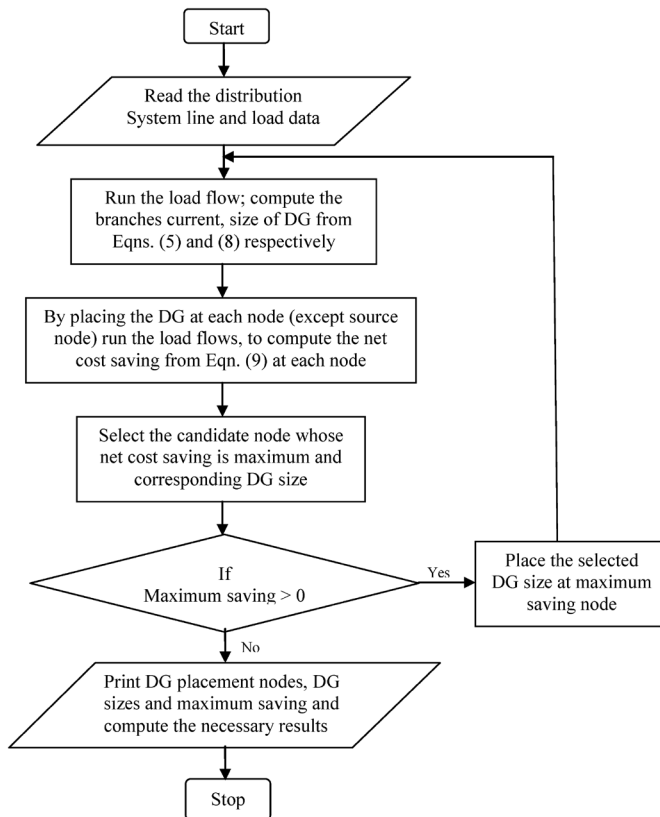


Figure 1. Flow chart for the proposed method

The grid search algorithm is applied by placing a DG to each bus, and changing the size of DG from 0% to 100% of total load power with the step size of 0.01MW. The total power losses are calculated by a complete power flow analysis for each case. The case with minimum losses determines the optimum location and size of DG. After that, the bus voltages are controlled whether the bus voltages are within the acceptable range. In 69-bus distribution test system, the optimum sizes of DG placed on each bus are determined by three different methods, shown in Figure 1. In addition, the calculated total power losses for each bus, where the optimum sized DG is added, are shown in Figure 2. As clearly be seen, the optimum size of DG at each bus is different and the difference between the results, which is obtained with three methods, are not significant. Particularly, both analytical methods, proposed in this article and in [10], almost give the same results for optimum sizes and estimated power losses. The optimum place of DG is bus 61 where the total power losses are minimal for this particular test system.

The optimum size of DGs and the total power losses for the corresponding DG sizes, determined by three approaches, are shown in Fig. 1 for 69-node distribution test systems. It is seen that the difference between the results of the three methods are negligible. Since both analytical methods are based on equivalent current injection technique, their results are almost in the same range. Absolute differences between the results are in the range of 20 kW for the optimum sizes. The estimated total power losses are again very close and the differences between them are in the ranges of 0.52 kW at most.

In Table 1, the results of the optimization procedure, computation time, the total power losses and net saving cost with and without DG for 69-node radial distribution system, are tabulated. It is seen that the total power losses are significantly reduced. In addition, the optimum placement and size of DG determined by all methods are in close agreement.

Again, due to fact that formulations are based on the equivalent current injection technique, the proposed and Acharya's method concur at most the same optimum size and placement for the test system. On the other hand, although approximate power losses differ from each other, the differences are in acceptable range. It is clear that the worst method according to computation time is the grid search algorithm. There are significant differences for the computation time between other methods, too. The difference becomes more significant when the system

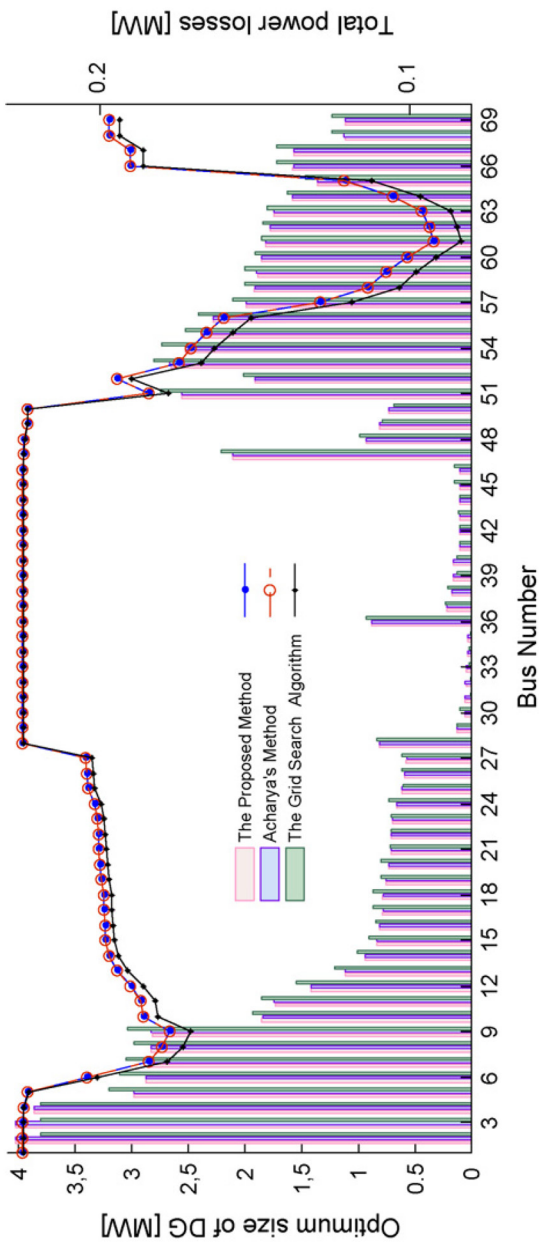


Figure 2. The optimal size for each bus and total power losses for corresponding DG in the 69-node distribution test system

Table 1. Summary of test results before and after DG placement of 69-node RDS

Parameters	Base Case	After DG Placement		
		Grid Search Algorithm	Acharya's Method	Proposed Method
Total active power loss (MW)	0.2246	0.0830	0.0835	0.0830
Total reactive power loss (MVar)	0.1020	0.0415	0.0416	0.0415
Vmin node	65	27	27	27
Min. Voltage of the system	0.90922	0.96803	0.96798	0.96810
DG placed node	-	61	61	61
DG size (MW) at unity power factor	-	1.8761	1.8015	1.8210
Net Saving (\$)	-	13152	13213	13255
CPU time in sec	-	275.92	4.109	0.278

size increased. For this test system the proposed method is almost 15 times faster than the Acharya's method. The difference is mainly due to the fact that Acharya's method needs to invert large matrices and also requires a second power flow.

Multiple DGs Placement

The proposed algorithm is also tested on 69-node radial distribution system with multiple DGs placement in the base case RDS. Table 2 depicts the optimal locations and corresponding optimal sizes of the DGs at node 61 and 17 with 1.421 MW and 0.512 MW respectively while Figure 3 shows the single line diagram by placing the DGs in 69-node radial distribution system. Maximum DGs have been placed in the 69-node radial distribution is two, beyond that the net saving is negative. It is observed that multiple DG placements are more beneficial as the net saving increases than the single DG placement. The more DG penetration is possible in case of multiple DG without encountering the voltage rise

Table 2. Summary of test results before and after DGs placement of 69-node RDS

Parameters	Base Case	Proposed Method
Total active power loss (MW)	0.2246	0.0715
Total reactive power loss (MVar)	0.1020	0.0358
Vmin node	65	65
Min. Voltage of the system	0.90922	0.98017
DG size (MW) at unity power factor	-	$P_{dg}(61) = 1.821$ $P_{dg}(17) = 0.512$
Net Saving (\$)	-	14154
CPU time in sec	-	0.397

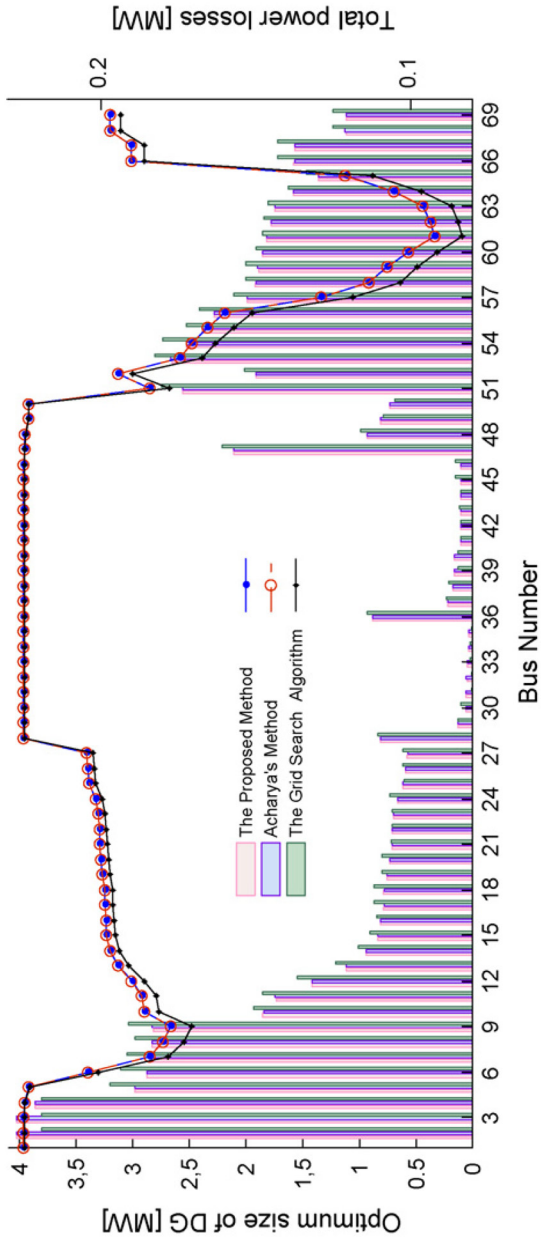


Figure 3. Single line diagram of the DGs placement of 69-node RDS

problem. Reduction in losses at nodes is better in case of multiple DGs placements rather than the single DG placement.

Figure 3 shows the real power losses at each branch for base case and after placing single DG and multiple the DGs. From Figures 2 and 3, it has been observed that when a DG is placed at 61 node, the branch current decreases in branches 1 to 8, branches 52 to 60, and there is no change in other branches—whereas when a DG is placed at node 17, the effective current decreases in branches 1 to 16 and there is no change in other branches. This in turn reduces the effect of the losses in the corresponding branches.

CONCLUSION

This study presents and evaluates a novel method which can be used to determine the optimal placement and sizing of DGs without use of admittance, impedance or Jacobian matrix with only one power flow for radial systems. The method is easier to implement and faster for a given accuracy. The optimal size and location of the DGs, which is determined by the method, is also evaluated simple algebraic equations. It is found that the proposed method is in close agreement with Acharya's method and the grid search algorithm and also applicable to the multiple DGs placement. It is appeared that the proposed method is faster than other methods in the computation time and it is appropriate for the distribution systems. Further developments towards global or system-wide optimization may include integrating and evaluating the reduction in power grid losses combined with the on-site benefits of cogeneration based DG.

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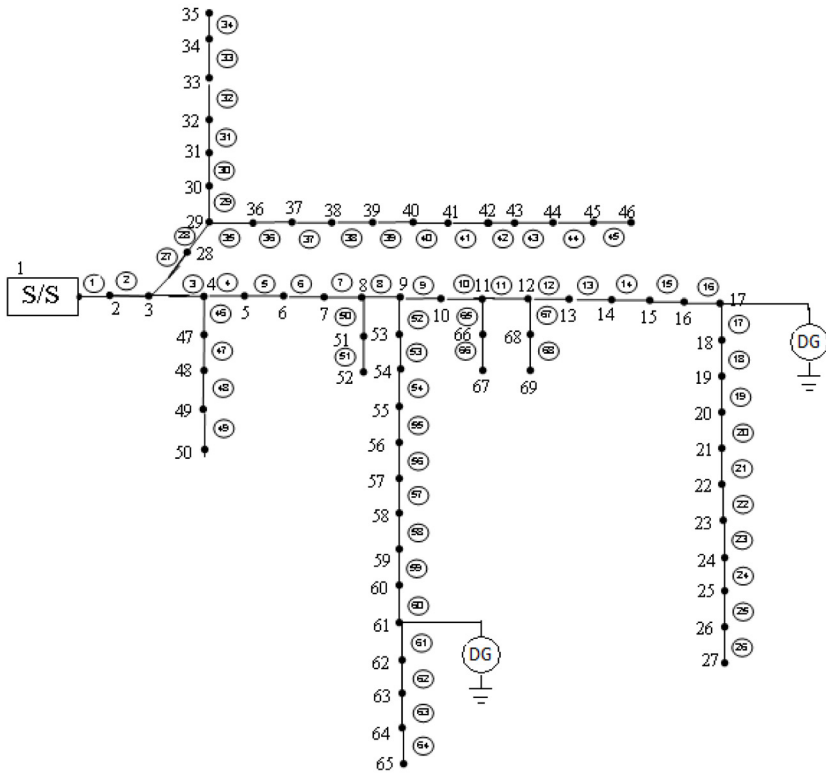


Figure 4. Branch real power losses for corresponding DGs placement by proposed method in the 69-node distribution test system

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