Multiple Distribution Generation Location in Reconfigured Radial Distribution System

Distributed generation in Distribution System

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Abstract. Distribution system reconfiguration is one of the major approaches to reduce the losses in the distribution system. With the integration of Distributed Generation (DG) in distribution system, there can be further improvement in voltage profile and further loss reduction in the reconfigured system. The main contribution of this paper is: (i) Proposing novel and modified novel power loss sensitivity methods for finding optimal locations for placement of multiple DGs, (ii) obtaining the sizes of distributed sources for reduced losses and better voltage profile, and (iii) Study of variation of multiple DG sizes taking the effect of reconfiguration of the distribution system, (iv) Study of the impact of DG sizes taking into consideration the power factor. The proposed method has been implemented and tested on IEEE 33 bus distribution system.

1. Introduction

Distributed Generation placement, load management, Network Reconfiguration and so on. The combination of Distribution system Reconfiguration and optimal placement of DG units is the effective way to reduce the losses in distribution network [1]. The network reconfiguration problem in a distribution system is to find a best configuration of radial network that gives minimum power loss while the imposed operating constraints are satisfied, which are voltage profile of the system, current capacity of the feeder, and radial structure of the distribution system[2]. A branch exchange-type heuristic algorithm has been suggested by S. Civanlar, et al [3], where a simple formula has been derived to determine how a branch exchange affects the losses. W. C. Wu, et al. [4] proposed an effective approach based on the particle swarm optimization with enhanced integer coding to determine the switch operation schemes for feeder reconfiguration. LW de Oliveira, et al. [5] proposed an optimal distribution network reconfiguration combined with optimal capacitor allocation to minimization of energy loss on radial distribution systems. In Ref. [6], a heuristic harmony search algorithm was used to solve reconfiguration problem in presence of DGs. The genetic algorithm developed using the edge window decoder technique for network representation and building up spanning trees, as well as efficient genetic operators in order to explore the search space for power distribution system reconfiguration with minimal losses [7]. Distribution feeder reconfiguration considering distribution generation based on particle swarm optimization presented in [8]. The optimal location of DGs, analytical methods for DG allocation, allocation based on losses reduction, heuristic methods, and a novel approach was presented in [9-14]. V.V.S.N.Mury, et al [15] proposed modified novel method to calculate the optimal location and DG sizes based on both real and reactive power losses at lagging power factor.
This paper proposed a method for finding optimal location for placing multiple DGs and their sizes to reduce the losses and to improve the voltage profiles. This paper is the extension of the previous work which was reported for single DG placement, however, the reconfiguration of the distribution system has not been considered [15]. Also the effect of multiple DGs allocation after reconfiguration of distribution has been studied in this paper. The reconfiguration of distribution system has been implemented based on the methodology reported in [18]. The data of IEEE 33 bus RDS is taken from [16-17]. The base MVA as 100 and base KV as 12.66 are taken for both the systems.

2. **Network Reconfiguration**

The Reconfiguration of 33 bus distribution systems have been considered to obtain the DG sizes and their impact on reduction of losses and improving the voltage profile. In the first stage, all candidate switches are closed to form Mesh system. After performing power flow, switches are ranked based on increasing current magnitude. The top ranked switch is considered to be opened first by keeping all other switches closed. Power flow is performed with the new feasible configuration and various constraints are checked. The two switches in the neighborhood of the opened switch are stored in a list to use them in second stage. This procedure is repeated till the radial system is obtained. In the second stage, a series of branch exchange operation will be performed by using the neighborhood switch list to obtain the optimal configuration. For 33 bus RDS [17], the real and reactive power losses are 202.66kW and 135.13kVAr with s33, s34, s35, s36 and s37 switches opened. After obtaining optimal configuration, the real and reactive power losses are 139.55kW and 102.3kVAr with s7, s9, s14, s32 and s37 switches opened. The minimum voltage is increased from 0.9131p.u to 0.9378p.u.

3. **Methodology**

3.1 **Optimal location and sizing of DGs using Modified Novel power loss sensitivity Method**

Modified Novel power loss sensitivity method [15] was proposed for single DG allocation at unity and lagging power factor. In this paper, the method is extended for multiple DGs allocation and their optimal sizes are determined at unity and lagging power factors.

3.1.1 Single DG allocation. Loss reduction by a single DG allocation. Let us consider the following:

\[ TLP = \text{total active power loss}, \]
\[ TLQ = \text{total reactive power loss}. \]
\[ I_i = \text{branch current}, R_i = \text{branch resistance}, I_{ai} = \text{active component of branch current}, I_{r0} = \text{reactive component of branch current}, TLP_0 = \text{loss associated with active component of branch current}, TLP_r = \text{loss associated with reactive component of branch current}. \]

\[ TLP = \sum_{b=1}^{b_{br}} I_i^2 R_i \]
\[ TLP = \sum_{b=1}^{b_{br}} I_i^2 R_i + \sum_{b=1}^{b_{br}} I_i^2 R_i \]
\[ TLP = TLP_a + TLP_r \]

a) **DG at unity power factor placed at bus ‘k’**.
\[ I_{adgk} = \text{active component of current supplied by DG at node ‘k’}, \]
\[ V_{dgk} = \text{voltage magnitude of DG at node ‘k’}. \]
Optimal size of DG at unity power factor is given as
\[ P_{dgk} = I_{adgk} * V_{dgk} \]

b) **DG at lagging power factor placed at bus ‘k’**.
\[ I_{adgk} = \text{active component of the current to be supplied by DG for maximum loss reduction at bus ‘k’}, \]
\[ I_{rdgk} = \text{reactive component of the current to be supplied by DG for maximum loss reduction at bus ‘k’}. \]

\[ I_{adgkp} = \frac{\sum_{i=1}^{I_i} I_{ai} R_i}{\sum_{i=1}^{I_i} R_i} \]  
\[ I_{adgkq} = \frac{\sum_{i=1}^{I_i} I_{ai} X_i}{\sum_{i=1}^{I_i} X_i} \]  
\[ I_{rdgkp} = \frac{\sum_{i=1}^{I_i} I_{r0} R_i}{\sum_{i=1}^{I_i} R_i} \]  
\[ I_{rdgkq} = \frac{\sum_{i=1}^{I_i} I_{r0} X_i}{\sum_{i=1}^{I_i} X_i} \]
The optimal size of DG can be calculated as

\[ S_{dgk} = \sqrt{P_{dgk}^2 + Q_{dgk}^2} \]  

Using eqns. (5), (12) and (13), optimal DG sizes can be obtained for unity and lagging power factor.

### 3.1.2 Multiple DG allocation

The concept of loss reduction by a single DG allocation can be extended for multiple DGs allocation. Let us consider the following:

- \( k_{dg} \) = number of buses compensated by DG
- \( I_{dg} \) = \( k_{dg} \)-dimensional vector consisting of DG currents
- \( \alpha \) = Set of branches from the source bus to the \( j^{th} \) DG bus (\( j=1, 2... k \)). In Figure 1, if three DGs (\( k=3 \)) are placed at buses 6, 15 and 30, the branch set \( \alpha_1 = [1 2 3 4 5], \alpha_2 = [1 2 3 4 5 6 7 8 9 10 11 12 13 14], \alpha_3 = [1 2 3 4 5 25 26 27 28 29] \)

#### a) DGs at unity power factor

The optimal DG currents for the maximum loss reduction is given by

\[ [G][I_{adg}] = [B] \]  

Where \( G \) is a \( k_{dg} \) x \( k_{dg} \) square matrix and \( B \) is a \( k_{dg} \)-dimensional vector. The elements of \( G \) and \( B \) are given by

\[ G_{ij} = \sum_{i \in \alpha_j} R_i \]  
\[ B_j = \sum_{i \in \alpha_j} I_{ai} R_i \]

Only the branch resistances and real currents in the original system are required to find the elements of \( G \) and \( B \). The DG currents at unity pf for the maximum loss reduction can be obtained from eqn. (15)

\[ [I_{adg}] = [G]^{-1}[B] \]  

Once the DG currents are known, the optimal DG sizes can be written as

\[ [P_{dg}] = [V_{dg}][I_{adg}] \]

Here \( V_{dg} \) is the voltage magnitude vector of DG buses.

#### b) DGs at lagging power factor

The optimal DG currents at lagging power factor for the loss reduction is given by

\[ [G][I_{pdc}] = [P] \]  
\[ [H][I_{qdc}] = [Q] \]

Where \( G \) and \( H \) are \( k_{dg} \) x \( k_{dg} \) square matrix and \( B, C, D, E, P \) and \( Q \) are \( k_{dg} \)-dimensional vector. The elements of \( G \) and \( H \) are given by
By calculating DG currents at lagging pf using eqns.(30-31), real and reactive powers supplied by DG can be calculated as:

\[ P_{dg} = I_{pdg} \times V_{dg} \times \cos \varnothing \]  
\[ Q_{dg} = I_{qdg} \times V_{dg} \times \sin \varnothing \]  

The optimal DG sizes can be written as

\[ S_{dg} = \sqrt{P_{dg}^2 + Q_{dg}^2} \]  

4. **Algorithm for DG Placement**

The computational steps involved in finding the optimal DG size and location to minimize the loss in distribution system are summarized as:

1) Run the base case load flow and obtain the base case power losses. Find the DG sizes at each node using eqn. (5) at unity pf and eqns. (12-13) at lagging pf.

2) Compensate each node (except the source node) with the DG sizes obtained in step 1 then select the node which gives maximum loss reduction, as a first DG location.

3) Update load data after placing the DG. Find the DG sizes at each node then identify the next compensating node at which maximum loss reduction is obtained.

4) Compensate all selected DG locations by using corresponding DG sizes found from eqn. (20) at unity power factor and eqns. (32-33) at lagging pf.

5) Repeat step 3-4 to determine next potential location for DG placement until it is found that there is no significant loss reduction that can be achieved by further DG placement.

Flow chart of proposed method for multiple DG allocation is shown in Figure 2.

5. **Results and Discussions**

Before reconfiguration of 33 bus distribution system, the base case losses are 202.665kw and 135.133kVAr. Using Novel method, DG with optimal size will be placed at each and every node and then the bus at which total power loss is minimum will be considered as optimal location. It is observed from the Figs. 3 and 4, the optimal location for placement of single DG is bus 6. After placing the DG of size 2487.44 kW at bus 6, the real and reactive power losses are reduced by 48.649% and 44.684% from its base case respectively. The minimum voltage has been increased from 0.91309p.u to 0.9498p.u. By assuming single DG is connected at bus 6 of base system and then repeat the same procedure for the next optimal DG location and it is found that the bus 15 is next optimal location. Simultaneously placing two DG units at buses 6 and 15 with the sizes of 1902.4556kW and 564.926kW, the real and reactive power losses are reduced by 55.66 % and 53.427% from its base case respectively. The minimum voltage has been increased to 0.95319p.u. Similarly by assuming two DG units are connected at buses 6 and 15 of base system, the same procedure has been repeated for finding next optimal location for placement of DG and it is found that the bus 25 is next optimal location. By placing three DG units at buses 6, 15 and 25 with the sizes of 1696.669kW and 564.926kW, the real and reactive power losses are reduced by 55.66 % and 53.427% from its base case respectively. The minimum voltage has been increased to 0.95331p.u. The voltage profile obtained with and without DG units has been shown in Figure 5.
However, after reconfiguration the base case losses are 139.549kW and 102.304kVAr. The optimal location of for placement of single DG is bus 30 and its size is 1065.797 kW Figure 6-7. The real and reactive power losses are reduced by 29.707% and 25.39% from its base case. The minimum voltage has been increased from 0.93782p.u to 0.9478p.u. With the placement of two DG units of sizes 1048.965kW and 934.547kW at locations 30 and 8 buses, the real and reactive power losses are reduced by 47.88% and 48.096% from its base case and the minimum voltage is increased to 0.973237p.u. With placement of three DG units of sizes of sizes 930.76kW, 914.3285kW and
1052.458kW at buses 30, 8 and 24 respectively, the losses are reduced by 57.79% and 56.74% from its base case and the minimum voltage has been increased to 0.973467p.u.

**Figure 5.** Voltage profile of 33 bus RDS without and with DGs at UPF– before reconfiguration.

The voltage profile obtained with and without DG units has been shown in Figure 8. Thus, before reconfiguration by placing three DG units of total size 3033.7927kW, the losses are reduced to 79.1376kW and 55.5914kVAr. However after reconfiguration by placing three DG units of total size 2897.7094kW, the real and reactive power losses are reduced to 58.899kW and 44.255kVAr. It is observed that the minimization of power loss is more with the DG placement after network reconfiguration.

**Figure 6.** Optimal DG sizes for 33 bus system at UPF – after reconfiguration.

The results are also obtained for DG allocation at 0.9 lagging power factor and are shown in Table 2. Before reconfiguration of 33 bus distribution system, the base case losses are 202.665 kW and 135.133kVAr. Using modified Novel method, DG with optimal size will be placed at each and every node and then the bus at which total power loss is minimum will be considered as optimal location. The optimal location for placement of single DG is bus 6. After placing the DG of size 3000.99kVA at bus 6, the real and reactive power losses are reduced by 68.03% and 62.63% from its base case respectively. The minimum voltage has been increased from 0.91309p.u to 0.9649p.u. By assuming single DG is connected at bus 6 of base system and then repeat the same procedure for the next optimal DG location and it is found that the bus 31 is next optimal location.

**Figure 7.** Variation of Total real power loss w.r.t DG size at UPF – after reconfiguration.
Simultaneously placing two DG units at buses 6 and 31 with the sizes of 2005.405kVA and 962.188kVA, the real and reactive power losses are reduced by 78.645% and 74.62% from its base case respectively. The minimum voltage has been increased to 0.96479p.u. Similarly by assuming two DGs are connected at buses 6 and 31 of base system, the same procedure has been repeated for finding next optimal location for placement of DG and it is found that bus 25 is next optimal location. By placing three DG units at buses 6, 31 and 25 with the sizes of 1787.983kVA, 962.1886kVA and 848.4035kVA respectively, the real and reactive power losses are reduced by 85.05% and 81.245% from its base case respectively. The minimum voltage has been increased to 0.96494p.u.. However, after reconfiguration the base case losses are 139.549kW and 102.304kVAr. The optimal location of for placement of single DG is bus 30 and its size is 1452.52kVA. The real and reactive power losses are reduced by 49.367% and 42.676% from its base case. The minimum voltage has been increased from 0.93782p.u to 0.9482p.u. With the placement of two DG units of sizes 1434.93kVA and 1027.382kVA at locations 30 and 8, the real and reactive power losses are reduced by 71.303% and 70.08% from its base case and the minimum voltage is increased to 0.97985p.u. With placement of three DG units of sizes of sizes 1312.71kVA, 1007.149kVA and 1144.936kVA at bases 30, 8 and 24, the losses are reduced by 83.391% and 80.758% from its base case and the minimum voltage has been increased to 0.980202p.u. Thus before reconfiguration by placing three DG units of total size 3598.575kVA, the losses are reduced to 30.2917kW and 25.3432kVAr. However after reconfiguration by placing three DG units of total size 3464.7947kVA, the real and reactive power losses are reduced to 23.1778kW and 19.68457kVAr. It is observed that the minimization of power loss is more with the DG placement after network reconfiguration and is given in the Table 2.

### Table 1. Results for 33 bus system without and with DG at UPF

| Bus number | Voltage (p.u.) |
|------------|----------------|
| 18         | 0.973467       |
| 19         | 0.973467       |

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**Figure 8.** Voltage profile of 33 bus RDS without and with DGs at UPF—after reconfiguration.
Table 2. Results for 33 bus system without and with DG units at 0.9 PF (lag)

| Before Reconfiguration 0.9 LPF | After Reconfiguration 0.9 LPF |
|-------------------------------|-------------------------------|
| With Out DG | 1 DG | 2 DG | 3 DG | With Out DG | 1 DG | 2 DG | 3 DG |
| DG Location | 6 | 6 | 31 | 6 | 31 | 25 | - | 30 | 30 | 8 | 30 | 8 | 24 |
| DG Size in kVA | - | 3000.999 | 2905.4059 | 962.1887 | 1787.983 | 962.1886 | 848.4035 | - | 1452.5225 | 1434.9341 | 1027.3826 | 1312.7097 | 1007.1490 | 1144.936 |
| Ptl (kW) | 202.665 | 64.792 | 43.2792 | 30.29177 | 139.548 | 9 | 70.658 | 40.0465 | 23.17783 |
| Tql (kW) | 135.133 | 50.502 | 34.29204 | 25.34372 | 102.300 | 4 | 58.645 | 36.60828 | 19.68457 |
| Min V (pu) | 0.913 | 0.964 | 0.964797 | 0.96494 | 0.9378 | 2 | 0.9482 | 0.979855 | 0.980202 |
| bus 18 | 18 | 18 | 18 | 18 | 32 | 33 | 14 | 14 |

6. References

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