Simultaneous and Incremental Approach for Optimal Placement and Sizing of Multiple Distributed Generations in Distribution System for Minimization of Power Losses

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Abstract. Several benefits have been obtained through integration of distributed generation in distribution systems. These advantages include reducing power losses, improving voltage profiles, and many more. These advantages can be accomplished and improved by optimizing the size and location of dispersed generations in the system. This paper introduces simultaneous and incremental approach using genetic algorithm for placement of multiple distributed generations to reduce power losses while keeping the network voltage profiles within specified limits. The algorithm is tested on IEEE 33-bus system and an Indian 85-bus system. It is clearly observed that, the proposed approaches provide optimal deployment of multiple distributed generations which reduces power losses and improves voltage profile.

1. Introduction

The definition of distributed generation (DG) is changing with time. In the literature, there is no unique definition of DG and it has been defined in many ways. DGs are the small power generators that can be connected to grid at any point close to the load. DGs which mainly include wind power, solar power, small hydropower and miniature gas turbine etc. is a supplement to centralized power generation. The combination of DGs and centralized generation can increase the advantages. Appropriate placement of DG in a distribution network can reduce power losses, distributed power investments, improve voltage profile and power quality, reduce interruption cost for network enforcing, total harmonic distortion etc. [1].

The extent to which DG reduces power losses and improves voltage profile depends on mode of operation, size and location of DGs [2]. Hence to maximize the benefits, it is very important to find the appropriate size of DG and the location in the network, as improper size and location can worsen the system operation and may lead to poor power quality and reliability, increase in system losses and costs. Many techniques have been proposed in the literature to solve the problem of placement of distributed generation. These methods can be classified into different groups: Analytical, Numerical, Heuristic, Meta-heuristic and some hybrid methods. [3] provides a survey of the state of the art of heuristic and metaheuristic techniques for optimal placement of DG.

Simultaneous placement of multiple DGs is proposed in [4], [5], [6], [7], [8] and incremental approach is proposed in [9], [10]. GA based approach is applied to obtain optimal location and size of
DGs in radial and networked system considering single and multiple DG placement with different load patterns [4]. Multi-location DG placement problem is solved by loss sensitivity factor and GA for minimizing loss and increasing the overall economic benefits [5]. A method based on genetic algorithm is used for optimally allocating distributed generation for profit, loss reduction and voltage profile improvement [6]. GA based approach has been used for allocation of DG in the power system with the mixed load models. The objective function is designed to minimize active and reactive power losses and to improve voltage profile [7]. Multi objective function is developed [8] considering power losses, voltage and reliability index and shift factor indices. It is solved by genetic algorithm and particle swarm optimization for various systems taking different type of loads. GA is utilized to select appropriate DG technology with optimal location and size for optimal operation of power system to minimize power loss in the network [9]. Nonlinear-constrained with single objective GA technique is employed for planning of renewable energy-based DGs [10]. GA is applied for reconfiguration and placement of DG [11]. Effect of distributed generation installation on power loss is presented in [12]-[13] using genetic algorithm method. A GA based on multi objective performance index is proposed [14] for determination of size and location of DG in distribution systems with different load models. Many parameters like loss reduction, voltage profile improvement, environmental effects, exploitation and maintenance expenses and cost of load prediction are considered in objective function and genetic algorithm based method is used to solve the problem of placement of DGs [15]. In [16] authors presented a structure to locate and size various types of DGs to improve the voltage profile, boost the voltage stability index, and reduce the energy losses. Efforts made to solve DG placement problem using genetic algorithm on various theoretical and practical system are summarized in table 1.

In this paper, simultaneous and incremental approach using Genetic algorithm (GA) is proposed to minimize the power losses by selecting the proper location and size of multiple distributed generations. The problem solved by genetic algorithm gives better results. The characteristics of genetic algorithm make it suitable to ill-structured optimization problems [17]. There can be various objective functions for enhancing the system such as minimization of operation cost, maximization of benefit/cost ratio, minimization of network loss, voltage profile improvement etc..

### Table 1. Summary of literature on genetic algorithm used for placement of DG

| Ref. | Objectives function | Number of DGs | Design Variable | Load model | System used |
|------|---------------------|---------------|----------------|------------|-------------|
| [4]  | Minimize the power loss | Multiple | Location, size | Constant power | 11 bus radial feeder, 6 bus system and 30 bus system |
| [5]  | Maximization of benefits | Multiple | Location, size | Variable load model | 33 and 69 bus system |
| [6]  | Multi objective | Multiple | Location, size | Constant power | 12-Bus radial rural distribution network |
| [7]  | Minimize the power loss and improve voltage profile | Multiple | Location, size | Constant power | 38- bus system |
| [8]  | Multi objective | Multiple | Location, size | Different load model-constant power | 33, 69 and 54 bus radial system |
| [9]  | Minimize the power loss | Multiple | Type, Location, size | Constant power | 14 bus system |
IEEE bus systems: 13, 30, 33, 69, 119

Most of the work in the literature presented simultaneous or incremental approach alone for placement of multiple DGs. In this paper the proposed method considers both the approaches for placement of multiple DGs. The proposed algorithm is analyzed on IEEE 33-bus system and an Indian 85-bus system. This paper is arranged as follows. Section II includes the problem definition and objective function considered in the work. Section III introduces the simultaneous and incremental approach and presents the methodology for solving the problem of optimal placement of multiple DGs. In Sections IV and V, the simulation results are discussed and conclusions are drawn respectively.

2. Problem Formulation
As the installation of distributed generation increases in the system, it is very important to consider the size and location of DGs. Inadequate position and size of DGs will increase power loss and degrade reliability. High-capacity DGs are not suggested to install in the network. Moreover, the complete capacity of DGs should be consumed within the limit of the network. Any effort to install DG with high capacity to export energy beyond the substation leads to very high loss due to inverse power flow through substation. Hence, the network configuration and the load on the distribution system play an important role while selecting the optimal size of DG for minimum system loss.

The main purpose of the paper is to employ the proposed approach to minimize power losses without violating the voltage limits and other constraints in the power system. The proposed simultaneous and incremental approach using Genetic algorithm is utilized to determine the optimal sizes and locations of the placement of multiple DGs at which the system loss becomes minimum. Figure 1 shows the optimization model used. In this paper, DG injecting real power with a fixed generator output is considered.

2.1 Objective Function
Consider the power flow from the bus $i$ to bus $j$ is $S_{ij}$ and from bus $j$ to bus $i$ is $S_{ji}$. The power loss in the line can be given by,

$$S_{Lij} = S_{ij} + S_{ji}$$  \hspace{1cm} (1)

$$S_{ij} = V_iI_{ij}^*$$  \hspace{1cm} (2)

$$S_{ji} = V_jI_{ji}^*$$  \hspace{1cm} (3)

Where, the current $I$ and the voltage $V$ at the corresponding bus are found from the power flow. $S$ is complex power flow with its real and imaginary part corresponding to the real and imaginary power loss on the line respectively. The amount of energy injections at all the nodes in the network represents losses. The total loss in the network can be calculated as:

| Reference | Objective Function | Methodology | Size and Location | System |
|-----------|--------------------|-------------|------------------|--------|
| [10]      | Minimize the power loss | Multiple | Location, size | Constant power | 33, 69 and 119 bus system |
| [11]      | Minimize the power loss | Multiple | Reconfiguration Location, size | Constant power | 33 bus system |
| [12]      | Minimize the power loss | Single | Location, size | Constant power | 30- bus system |
| [13]      | Minimize the power loss | Single | Location, size | Constant power | 33- bus system |
| [14]      | Multi objective | Single | Location, size | Different load model-variable power | 16 and 37- bus system |
| [15]      | Multi objective | Single | Location, size | Constant power | 13- bus network |
| [16]      | Multi objective | Single | Location, size | Variable load model | 33 bus system |
\[ P_{\text{loss}} = \sum_{k=1}^{\text{nbr}} \text{real}(S_{lk}) \]  

(4)

Where, ‘nbr’ is number of transmission lines in the network. The objective function is to reduce \( P_{\text{loss}} \) according to the constraints of power flow. DG is regarded as negative loads on buses; therefore, the equation of the power balance has been modified as \( P_{\text{di}} = P_{\text{di}} - P_{\text{dgi}} \), where \( P_{\text{di}} \) - Power demand at bus ‘i’ and \( P_{\text{dgi}} \) – Power from DG connected at bus ‘i’. There is no change in reactive power balance equations as DG is producing only real power. In this paper, loss minimization has been used as a fitness function, and the GA has been used to optimize the fitness function.

2.2 Operating Constraints
The operating constraints of the problem are:

2.2.1 Equality constraints: Summation of all incoming powers including power generated by ‘m’ DG units should be equal to outgoing powers and power losses for distribution system.

\[ P_{\text{gs}} + \sum_{i=1}^{m} P_{\text{DGi}} = P_{\text{load}} + P_{\text{loss}} \]  

(5)

Where, \( P_{\text{gs}} \) – Power available at substation from central generation, \( P_{\text{load}} \) – Total load of on the substation.

2.2.2 Inequality constraints:
The injected power by increasing DG unit is limited by their maximum and minimum limits as:

\[ P_{\text{minDGi}} \leq P_{\text{DGi}} \leq P_{\text{maxDGi}} \]  

(6)

Bus voltage limits (as per Indian standard ±5% margin)

\[ 0.95 \text{ pu} \leq V_i \leq 1.05 \text{ pu} \]  

(7)

3. Simultaneous and incremental approach using Genetic Algorithm
To reduce the losses with high value and to compensate the demand in a power system having no DG, many DGs can be placed simultaneously as shown in figure 2(a). It is also possible that the system may
have some penetration of DG, and to improve the system, it is needed to deploy more DGs. In that case incremental approach is suitable to solve the problem as shown in figure 2(b).

![Figure 2(a). Simultaneous approach of placement of DGs](image)

![Figure 2(b). Incremental approach of placement of DGs](image)

If integration of nDG in the distribution network doesn’t violate the network regulations and sufficient funding is available then system planner can add appropriate number of DGs all at once i.e. simultaneously. But, sometime it is not possible to invest large amount at the same time and adding more DG in the system may have regulation problem then incremental approach is suitable. In incremental approach it is important to consider system data with DG to place next DG.

Genetic algorithm is a metaheuristic approach belonging to a larger class of evolutionary algorithms. It is used to solve constrained and unconstrained search and optimization problems. This uses natural selection controlled by reproductive biological process. GA requires: genetic representation of solution domain and fitness function. The most important components in a GA consist of initialization, population generation, evaluation, selection, crossover and mutation.

As initial approach, a group of chromosomes called population are used. The quality of initial solutions is evaluated through the fitness function extracted from the objective function. Three GA operators generate a new array of candidate solutions with an improved fitness value over each generation (i.e. reproduction, crossover and mutation). The GA framework is explained below:

Step 1: Initialization- Randomly generates an initial population. The chromosome consists of DG location (‘loc’) and DG size (‘PDG’). The proposed chromosome will be:

\[ X_i = [loc_1, loc_2, \ldots, loc_n, PDG_1, PDG_2, \ldots, PDG_n] \]

Where \( i = 1, 2, 3, \ldots, m \). The variable \( m \) indicates the number of locations and DGs. ‘n’ is number of buses in the radial or networked system.

Step 2: Evaluation- evaluate fitness function after calculating the power loss

Step 3: Selection- select the best population from the current population.

Step 4: Crossover- generate offspring using crossover function with crossover probability \( P_c = 0.8 \)

Step 5: Mutation- Apply the mutation function for each population generated in step 3 with the mutation probability \( P_m = 0.01 \).

Step 6: Termination- if the termination criterion (Maximum iterations and constraints) is fulfilled then halt. Otherwise update iterations and return to step 2.

Algorithmic flowcharts for the proposed simultaneous and incremental approach are shown in figure 3 and figure 4.
4. Results and Discussion
The optimal locations and sizes for the placement of multiple DGs are obtained by simultaneous and incremental approach. The proposed approach is implemented in MATLAB. The line flows are computed using Newton-Raphson method. The success of the method is tested on IEEE 33-bus [18] and Indian 85-bus test system [19].
4.1 IEEE 33-bus system
Figure 5 represents single line diagram of IEEE 33-bus test system and its line and bus data are taken from [18]. The system consists of 32 sectionalizing branches at nominal voltage of 12.66 kV and a total system load of 3.72 MW and 2.3 MVAR.

![Figure 5. Single line diagram of IEEE 33-bus system](image)

4.1.1 Case I: Simultaneous approach for placement of multiple DGs
It is considered that initially there is no DG in the system. Appropriate location and size of single DG, two DG and three DG is obtained using the algorithm as shown in algorithmic figure 3 and figure 4.

Table 2 shows the power losses, % reduction in losses and minimum and maximum voltage values before and after installation of single DG, two DGs and three DGs simultaneously. Before DG installation, real losses of the system are 212.2 kW.

| Options                        | Without DG | Single DG | Two DG  | Three DG |
|--------------------------------|------------|-----------|---------|----------|
| Optimum bus locations for placement of DG | -          | 6         | 30      | 16       |
| Optimal size of DG (kW)        | -          | 2641.0    | 1277.6  | 685.3    |
| Total active power loss (kW)   | 212.2      | 111.57    | 88.364  | 80.112   |
| Reduction in power loss (%)    | -          | 47.42     | 58.36   | 62.24    |
| Minimum voltage in p.u         | 0.903      | 0.943     | 0.972   | 0.966    |
| Maximum voltage in p.u         | 1.00       | 1.00      | 1.00    | 1.00     |

After installation of single DG injecting real power only, there is reduction in losses by 47.42% with the value of loss as 111.57 kW and the optimal location is 6 with the size 2641 kW. In two DG case the optimal locations are bus 13 and bus 30 with the size 895.8 kW and 1277.6 kW respectively. The optimal locations for three DGs are obtained as 25, 16 and 31 giving minimum losses. Losses are reduced by 62.24%. Further increase in number of DGs does not reduce the losses by large amount. Figure 6 gives the voltage profile at different buses when the single and multiple DGs are placed at optimal location with appropriate size for case I. Due to placement of DG the voltage variations are reduced. With addition of 4 and more number of DGs, the losses get reduced, but the difference in loss reduction is very small.
4.1.2 Case II: Incremental approach for placement of multiple DGs

In this case it is assumed that already there is some penetration of DG in the system. Optimal location and size for placement of next DG is decided on the basis of previously connected DGs.

Table 3 shows the power losses, % reduction in losses and minimum and maximum voltage values before and after installation of single DG, two DGs and three DGs for case II. The system has DG of size 2641 kW already connected at bus 6. Now to add new DG in the system, genetic algorithm is applied by generating the population for only two variables – one for next DG location and DG size.

The next optimal DG size is 472.9 kW at bus 15 which will give minimum losses. Further, for placement of next DG, it is assumed that two DGs are connected at bus 6 and 15 of size 2641 kW and 472.9 kW respectively. Only two variables are generated and GA is executed and the optimal location for third DG is at bus 25 with its optimal size 623.2 kW. By adding one more DG there is small reduction in losses but the cost associated with DG increases with large amount. Figure 7 shows the voltage profile of each bus after placement of DGs at proper location.

The placements of one, two and three DG have improved the voltage profile of the distribution system. From figure 6 and 7, it is observed that the voltages are below the standard values at buses 6-18 and 26-33 when DG is not placed in the network. With the DG, voltage values are within acceptable range and it is improved at all buses. The highest percentage improvement of voltage is at buses 13-18 while buses 2-6 and 19-22 has lowest voltage improvement. This voltage profile improvement depends on the location of DG whether it is further connected to branch or not.

Table 3. Simulation results of case II for IEEE 33-bus system

| Options                                      | Without DG | Single DG | Two DG | Three DG |
|----------------------------------------------|------------|-----------|--------|----------|
| Bus number at which DG already present in the System | -          | -         | 6      | 6 & 15   |
| Next optimum location for placement of DG    | -          | 6         | 15     | 25       |
| Optimal size of DG (kW)                      | -          | 2641.0    | 472.9  | 623.2    |
| Total active power loss (kW)                 | 212.2      | 111.57    | 97.301 | 90.02    |
| Reduction in power loss (%)                  | -          | 47.42     | 54.15  | 57.49    |
| Minimum voltage in p.u                       | 0.903      | 0.943     | 0.962  | 0.964    |
| Maximum voltage in p.u                       | 1.00       | 1.00      | 1.00   | 1.00     |
Figure 7. Voltage magnitudes at each bus for Case II for IEEE 33-bus system after placement of DG

4.2 Indian-85 bus system

This system consists of 85 buses and 84 sectionalising branches shown in figure 8. The bus, line and generator data have been taken from [19]. The total real power demand of the system is 2.549 MW and the reactive power demand is 2.601 MVAR. The base values are 100MVA, 11 kV. The base case power loss without DG is 349.1 kW. This RDS is solved for P-type DG units i.e injecting only real power, using the proposed GA algorithm. The minimum voltage is at the 54th bus.

Figure 8. Single line diagram for Indian 85-bus system [19]
4.2.1 Case I: Simultaneous approach for placement of multiple DGs

Table 4 shows the power losses, percent reduction in losses and minimum and maximum voltage values before and after installation of single DG, two DGs and three DGs. Before DG installation real losses of the system were 349.1 kW.

| Options                              | Without DG | Single DG | Two DG   | Three DG |
|--------------------------------------|------------|-----------|----------|----------|
| Optimum bus locations for placement of DG | -          | 8         | 9        | 9        |
| Optimal size of DG (kW)              | -          | 2474.0    | 591.2    | 851.2    |
| Total active power loss (kW)         | 349.1      | 192.2     | 170.0    | 166.44   |
| Reduction in power loss (%)          | -          | 44.93     | 51.30    | 52.32    |
| Minimum voltage in p.u               | 0.899      | 0.969     | 0.985    | 0.985    |
| Maximum voltage in p.u               | 1.05       | 1.05      | 1.05     | 1.05     |

After installation of single DG injecting real power only, there is reduction in losses by 44.93 percent with the value of loss as 192.2 kW and the optimal location 8 with the size 2474.0 kW. For multiple DG installation, it is considered that there is no DG in the system and two or three DGs are required to be connected. For two DGs, population for four variables are generated- two for location and two for size. In two DG case the optimal locations are bus 36 and bus 9 with the size 591.2 kW and 1597.5 kW respectively.

Figure 9. Voltage magnitudes at each bus for Case I for Indian 85-bus system after placement of DG
In three DG case, the population for 6 variables- three for each location and size is generated. The optimal locations for three DGs are obtained as 69, 33 and 9 giving minimum losses. Losses are reduced by 52.32%. Further increase in number of DGs does not reduce the losses significantly.

Figure 9 illustrates the voltage magnitudes for Indian 85-bus system when single DG, two DG and three DG are connected with their appropriate size at suitable location.

4.2.2 Case II: Incremental approach for placement of multiple DGs
Optimal location and size for placement of next DG is decided on the basis of previously connected DGs. The value of power losses, % reduction in losses and minimum and maximum voltage values before and after installation of single, two and three DGs are included in table 5.

Table 5. Simulation results of case II for Indian 85-bus system

| Options                                      | Without DG | Single DG | Two DG |
|----------------------------------------------|------------|-----------|--------|
| Bus number at which DG already present in the System | -          | -         | 8      |
| Next optimum location for placement of DG    | -          | 8         | 48     |
| DG optimal size (kW)                         | -          | 2474.0    | 2474.0 |
| Total active power loss (kW)                 | 349.1      | 192.2     | 179.8  |
| Reduction in losses (%)                      | -          | 44.93     | 48.49  |
| Minimum voltage in p.u                       | 0.899      | 0.969     | 0.999  |
| Maximum voltage in p.u                       | 1.05       | 1.05      | 1.05   |

The system has DG of size 2474.0 kW is already connected at bus 8. The next optimal DG size is 371.4 kW at bus 48 which will give minimum losses. Figure 10 illustrates the voltage magnitudes for Indian 85-bus system when one or multiple DGs are connected with their appropriate size at suitable location.

Figure 10. Voltage magnitudes at each bus for Case II for Indian 85-bus system after placement of DG
With single DG placed at bus 8 the loss is 192.2 kW with reduction of 42.93 % from its base loss. After addition of two DGs the loss reduction is 48.49 %.

From the case II for 85-bus system it is observed that even though DG is previously connected in the system, the losses reduced by 12.40 kW, but it violates the power balance constraints of the system and it is not the feasible solution as it does not satisfy the standards of the grid. From figure 9 and 10, it is observed that the voltages are below the standard values at buses 10-14 and 25-85 when DG is not placed in the network. With the DG voltage values are within acceptable range and it is improved at all buses. The highest percentage improvement of voltage is at buses 30-36 and 40-56 which is around 15 to 21 percent while bus 22 and 20 has lowest voltage improvement for one or more DG placement. The voltage profile improvement is dependent on the location of DG whether it is further connected to branch or not.

5. Conclusion
Inappropriate allocation of DG sources in the power system can result in increased power losses, as well as inappropriate operation of the system. To achieve the maximum environmental, economic and technical benefits, DG should be installed in the optimal position. This paper presented simultaneous and incremental approaches using GA algorithm to obtain optimum locations and sizes of multiple DGs in radial distribution system to minimize total power loss. The use of simultaneous or incremental approach depends on the availability of sufficient amount of funding and constraints in technical and environmental regulation. Loss reduction and voltage profile improvement is observed with the increase in penetration of DG. However, this trend reverses after a certain number of locations and size of DG.

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