*Indian Journal of Natural Sciences* *www.tnsroindia.org.in ©IJONS*

*Vol.14 / Issue 81 / Dec / 2023 International Bimonthly (Print) – Open Access ISSN: 0976 – 0997*

**RESEARCH ARTICLE**

# Multiple Optimal Placement and Sizing of Distributed Generators for Minimizing Losses and Improving Voltage Profile in Distribution Systems

Suma Deepthi Veeraganti[1]*, K.Anitha Reddy[2] and Ramchandra Nittala[3]

[1]Assistant Professor, Department of Electrical and Electronics Engineering, G.Narayanamma Institute of Technology and Science (For Women), (Affiliated to Jawaharlal Nehru Technological University), Hyderabad, Telangana, India.

[2]Assitant Professor, Department of Electrical and Electronics Engineering, Malla Reddy Engineering College (Autonomous), (Affiliated to Jawaharlal Nehru Technological University) Hyderabad, Telangana, India.

[3]AssociateProfessor and HoD, Department of Electrical and Electronics Engineering, St.Martin's Engineering College (Affiliated to Jawaharlal Nehru Technological University) Hyderabad, Telangana, India.

Received: 12 Aug 2023 Revised: 25 Sep 2023 Accepted: 01 Dec 2023

***Address for Correspondence**
**Suma Deepthi Veeraganti**
Assistant Professor,
Department of Electrical and Electronics Engineering,
G.Narayanamma Institute of Technology and Science (For Women),
(Affiliated to Jawaharlal Nehru Technological University),
Hyderabad, Telangana, India.
Email:



**ABSTRACT**

This paper proposes a hybrid method based on analytical expressions incorporating particle swarm optimization (PSO) to find the optimal location and optimal DG size with an objective of minimizing losses and improving voltage profile. DG optimization problem is also solved with an objective of minimizing power loss only. The proposed method is tested on 33 and 69 radial distribution systems.

**Keywords** : Analytical expression; particle swarm optimization; multiple DG allocation; loss reduction; voltage profile improvement.

## INTRODUCTION

Due to the increase in power demand, the need for generation of power is steadily increasing. To give uninterrupted service to consumers, it is necessary to increase the penetration of distributed generation into distribution systems.

Due to the problems of poor voltage regulation, shortage of transmission capacities and increased environmental concerns, the conventional methods of supplying power could not meet the whole demand. To overcome this, distributed generator (DG) has become the alternative source for power supply.

Apart from meeting the energy demand, the optimal location and size of DG units can reduce distribution losses; improve voltage stability and voltage profile. Loss minimization is an important factor in planning and operation of DG. Many techniques have been proposed in literature to find the optimal allocation and optimal size of DG. In ref [1], genetic algorithm has been implemented for placing distributed generator in power distribution system to reduce losses. But this method is computationally demanding and slow in convergence. Wang C and Nehrir proposed an analytical method for optimal placement in radial as well as meshed system. But in this paper, a fixed DG size was considered for analysis. A 2/3 rule which is traditionally applied for capacitor allocation has been applied for DG allocation in ref [3] but this technique cannot be applied to meshed distribution system. N. Acharya, P. Mahat, and N. Mithulananthan proposed a new method to find the optimal size and location of DG for minimizing the total power lossesin primary distribution systems. In this paper, DG capable of injecting real power was only considered. Loss sensitivity factor method which was used to solve the capacitor allocation problem when applied for DG allocation as in ref [5] needs a large number of load flow solution.

In this paper, an improved analytical method is proposed for allocation of multiple DGs. Unlike the previous methods, DG is capable of injecting both real and reactive powers. As DG units can supply a portion of total power to loads, the feeder current reduces from the source to the DG location.

## LOAD FLOW SOLUTION

The load flow solution is obtained by using two developed matrices – the bus injection to branch current (BIBC) and the branch current to bus voltage matrix (BCBV). A simple matrix multiplication gives the load flow solution. This method is proposed in ref [6].

**Algorithm:**

1. Input line and load data of distribution network.
2. Form the BIBC and BCBV matrices.
3. Obtain DLF matrix by multiplying BIBC and BCBV matrices.
4. Set iteration count t = 0.
5. Obtain the values of current injection at the t-th iteration using

$$I_l^t = conj(\frac{S_l}{V_l^t})$$

6. Calculate the change in voltage using

$$[\Delta V^{t+1}] = [DLF][I^t]$$

7. Update the voltage values using

$$[V^{t+1}] = [V^0] + [\Delta V^{t+1}]$$

Repeat steps 5 to 7 until iteration t is equal to maximum iteration.

9. If iteration = maximum iteration, calculate branch currents. Branch current ($i_{br}$) = BIBC*I
10. For each branch calculate real loss and reactive loss.

Real loss = $|i_{br}|2$* branch resistance
Reactive loss = $|i_{br}|2$* branch reactance

## MULTIPLE DG ALLOCATION AND DG SIZE

An analytical method is proposed in this paper to allocate multiple DG units for achieving high loss reduction in a distribution system.

### DG size expression

The expressions used to find the DG size at each bus [7,8] is given by (1) and (2)

$$P_{DG_l} = \frac{a_{ll}(P_{D_l} + uQ_{D_l}) - G_l - uH_l}{u^2 a_{ll} + a_{ll}} \quad (1)$$

$$Q_{DG_l} = uP_{DG_l} \quad (2)$$

in which,

$$u = (sign)\tan(\cos^{-1}(PF_{DG})) \quad (3)$$

sign = +1 for DG injecting reactive power

sign = -1 for DG consuming reactive power

$$G_l = \sum_{\substack{m=1 \\ m\neq l}}^{N} (a_{lm}P_m - b_{lm}Q_m)\; H_l = \sum_{\substack{m=1 \\ m\neq l}}^{N} (a_{lm}Q_m + b_{lm}P_m) \quad (4)$$

Where

$$a_{lm} = \frac{r_{lm}}{V_l V_m}\cos(\theta_l - \theta_m);\; b_{lm} = \frac{r_{lm}}{V_l V_m}\sin(\theta_l - \theta_m) \quad (5)$$

| | |
|---|---|
| $V_l\angle\theta_l$ | voltage at the $l^{th}$ bus; |
| $Z_{lm} = r_{lm} + jx_{lm}$ | $lm^{th}$ element of impedance matrix; |
| $P_l$ and $P_m$ | real power injections at the $l^{th}$ and $m^{th}$ buses, respectively, |
| $Q_l$ and $Q_m$ | reactive power injections at the $l^{th}$ and $m^{th}$ buses, respectively; |
| N | number of buses |

Types of DG

There are four types of DG depending on the injection of real and reactive powers.

Type 1: DG capable of injecting both P and Q

The power factor of the DG is in between 0 and 1. By using equations (1) and (2), the optimal size of DG at each bus for the loss to be minimal is obtained.

Type 2: DG capable of injecting P but consuming Q.

Similar to the type 1 DG, the optimal size is obtained by using equations (1) and (2).

Type 3: DG capable of injecting P only

As the DG is injecting only real power, the power factor of the DG is one. The optimal size of DG at each bus [8] for minimum power loss is given by [8]

$$P_{DG_l} = P_{D_l} - \frac{1}{a_{ll}} \sum_{\substack{m=1 \\ m\neq l}}^{N} (a_{lm}P_m - b_{lm}Q_m) \quad (6)$$

Type 4: DG capable of injecting Q only

DG is capable of injecting only reactive power and the power factor of the DG is zero. The optimal size of the DG at each bus [8] for minimum power loss is given by

$$Q_{DG_l} = Q_{D_l} - \frac{1}{a_{ll}} \sum_{\substack{m=1 \\ m\neq l}}^{N} (a_{lm}Q_m + b_{lm}P_m) \quad (7)$$

Calculation of combined power factor

The power factor of the system is obtained by using the following equation

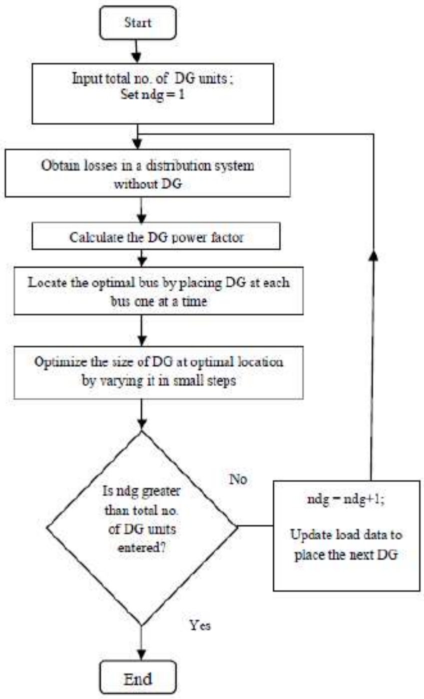
$$PF_D = \frac{P_D}{\sqrt{P_D^2 + Q_D^2}} \quad (8)$$

$$P_D = \sum_{l=1}^{N} P_{Dl};\; Q_D = \sum_{l=1}^{N} Q_{Dl}$$

**Algorithm to find optimal location and size**

Step 1: Input the number of DG units to be integrated.
Step 2: Obtain losses for the case without DG using the load flow solution described above.
Step 3: Calculate the power factor of DG using (8).
Step 4: Obtain the values of PDG and QDG using (1) and (2).
Step 5: calculate the loss by placing the DG at each bus one at a time using the BIBC and BCBV load flow method.
Step 6: The bus with minimum loss gives the optimal location.
Step 7: Optimize the PDG value at optimal location by varying it in small steps.
Step 8: The optimal size of DG is the size which gives minimum loss.
Step 9: To integrate the next DG, load data is updated by placing the DG with optimal size obtained in previous step.
Step 10: Repeat steps 2 to 9 until all DG units have been integrated

**Flow chart**




**PARTICLE SWARM OPTIMIZATION**

In this paper, Particle swarm optimization (PSO) algorithm is used to optimize the size of DG. PSO is a technique proposed by Kennedy and Eberhart [9] by observing the behaviour of bird flocking or fish schooling. In this technique, each individual adjusts its position depending on its own experience – known as pbest and on the experience of neighbouring particle-known as gbest. It generates random values of a given parameter such as DG size, location, velocity etc.

**Key terms**

particle/individual/agent: each individual in the swarm; swarm: the entire collection of particles; population size: number of random values considered in between maximum and minimum values of a particular parameter; fitness: value that gives best solution to the optimization problem; pbest (personal best): the position in parameter space of the best fitness returned for a specific particle; gbest (global best): the position in parameter space of the best fitness returned for the entire swarm; Vmax: the maximum velocity value allowed in a given direction;

**Basic algorithm**

Step 1: Generate an initial population of velocities and DG sizes randomly.
Step 2: Initialize the iteration with k = 1.
Step 3: Calculate the objective function at each bus.
Step 4: For first iteration, pbest will be equal to the values of the objective function obtained for each particle/bus and gbest is the value with minimum value in the values of pbest.
Step 5: Increment the iteration count and update the values of velocities and DG sizes using (9) and (10)

$$v_{id}^{k+1} = \omega v_{id}^{k} + c_1 rand * (pbest_{id} - s_{id}^{k}) + c_2 rand * (gbest_d - s_{id}^{k}); \quad (9)$$

$$s_{id}^{k+1} = s_{id}^{k} + v_{id}^{k+1}; \quad (10)$$

Where

$$\omega = \omega_{max} - \left(\frac{\omega_{max} - \omega_{min}}{maxitr}\right) * itr; \quad (11)$$

$$\omega_{max} = 0.9; \ \omega_{min} = 0.4.$$

Step 6: Compare the objective value obtained at a particular bus with its previous iteration. If it is less than value obtained in previous iteration, set this value as current pbest. Gbest is the best value (i.e. with minimum objective value) among current pbest values.
Step 7: If iteration = maximum iteration, go to step 8. Otherwise go to step 3.
Step 8: gbest gives the optimal DG sizes.

**MULTI-OBJECTIVE FUNCTION**

Here, three objective functions viz. f1, f2 and f3 are combined into one for minimising loss and improving voltage stability and voltage profile. The three parameters $f_1$, $f_2$ and $f_3$ are in p.u.

**A objective function**

The multi-objective function expression is given by

$$f = \min(f_1 + k_1 f_2 + k_2 f_3); \quad (12)$$

$f_1$ is the loss in the distribution system calculated using the load flow solution described above.
$f_2$ is the voltage profile given by

$$f_2 = \sum_{n=2}^{N}\left(|V_n - V_{rated}| - (V_n - V_{rated})\right); \quad (13)$$

$f_3$ is the network voltage stability index is given by

$$f_3 = \frac{1}{min\{SI_2, SI_3, \ldots\ldots, SI_N\}}; \quad (14)$$

Where

$$SI(n) = |V_m|^4 - 4[P_n(n)R_n + Q_n(n)X_n]|V_m|^2 - 4[P_n(n)R_n + Q_n(n)X_n]^2 \quad (15)$$

n = receiving bus number;
m = bus number that is sending power to bus n;
br = total number of branches;
$C_1$, $C_2$ (constants)= 2 ;
$V_{rated}$ = rated voltage ( 1 p.u.);
$k_1$ = penalty coefficient ( $k_1$ = 0.6 );
$k_2$ = penalty coefficient ($k_2$ = 0.35);
P = net real power flow;
Q = net reactive power flow.

## METHODOLOGY

The objective of minimizing loss, improving voltage profile and increasing voltage stability is achieved by using analytical expressions incorporating PSO. To determine the optimal locations of DG units, the bus with minimum functional value f is located. The DG location and size are determined similar to the method followed in obtaining optimal location and size of DG where the objective is to minimize only loss. But instead of changing the DG size in small steps, random sizing of DG is carried out by using PSO algorithm as described above. The optimal DG size is the size for which the objective function f is minimal.

## RESULT

Table 1 and Table 2 presents the results of the optimal locations and sizes for loss minimization objective and multiple objective function for 33 and 69 distribution systems respectively. It is observed from tables 1 and 2 that the voltage profile is improved and DG size is reduced using multi-objective function. The DG size and location has been mentioned for single DG placement, two DG units placement and three DG units placement. It is observed from the table that there is a high loss reduction when three DG units are integrated in distribution system.

## CONCLUSION

In this paper, the optimal locations are obtained using analytical expressions and the size of DG obtained from equations (1) and (2) is fine tuned using PSO algorithm considering the real power loss, voltage profile and voltage stability index. These values are compared with the optimal sizes of DG which are obtained considering only loss minimization.

## REFERENCES

1. Mithulananthan N, Oo Than, Van Phu Le. Distributed generator placement in power distribution system using genetic algorithm to reduce losses. TIJSAT 2004; 9(3):55–62.
2. Wang C, Nehrir MH. Analytical approaches for optimal placement of distributed generation sources in power systems. IEEE Trans PWRS 2004;19(4):2068–76.
3. H. L. Willis, “Analytical methods and rules of thumb for modeling DG-distribution interaction,” in Proc. IEEE Power Eng. Soc. Summer Meet. 2000, 3, pp. 1643-1644.
4. N. Acharya, P. Mahat, and N. Mithulananthan, “An analytical approach for DG allocation in primary distribution network,” Int. J. Elect. Power Energy Syst., vol. 28, no. 10, pp. 669-678, Dec. 2006.
5. Griffin T, Tomosovic K, Secrest D, Law A. Placement of dispersed generations systems for reduced losses. In: Proceedings of the 33rd Hawaii international conference on sciences, Hawaii, 2000.
6. Jen-Hao Teng, “A direct Approach for Distribution System Load Flow Solutions” IEEE transactions on Power Delivery, Vol.18, No.3, July 2003
7. D. Q. Hung, N. Mithulananthan, and R. C. Bansal, “Analytical expressions for DG allocation in primary distribution networks,” IEEE Trans. Energy Convers., vol. 25, no. 3, pp. 814-820, Sep. 2010.
8. D. Q. Hung and N. Mithulananthan, “Multiple Distributed Generator Placement in Primary Distribution Networks for Loss Reduction,” 2011.
9. Kennedy JF, Eberhart RC. Particle swarm optimization. In: Proceedings of the IEEE international conference on neural networks, vol. 4. Perth, Australia; 1995, p. 1942–48

**Table I: 33 Bus System - PQ Injection**

| No. of DGs | Objective | DG Location | DG size (KVA) | $f_{Loss\ (kW)}$ | $f_{VP}$ | $f_{VSI}$ |
|---|---|---|---|---|---|---|
| Without DG | | - | - | 211.00 | 3.62 | 1.50 |
| 1 | Loss minimization | 6 | 3103.00 | 68.18 | 1.1580 | 1.1857 |
| | Loss minimization, voltage profile improvement and voltage stability | 6 | 3257.60 | 68.49 | 1.0532 | 1.1731 |
| 2 | Loss minimization objective | 6, 15 | 2936.77, 505.76 | 52.02 | 0.3543 | 1.0893 |
| | Loss minimization, voltage profile improvement and voltage stability | 6, 16 | 2822.22, 488.08 | 54.61 | 0.3035 | 1.0796 |
| 3 | Loss minimization objective | 6, 15, 25 | 2384.21, 505.76, 727.3 | 40.30 | 0.2807 | 1.0875 |
| | Loss minimization, voltage profile improvement and voltage stability | 6, 16, 32 | 2352.18, 460.97 523.33 | 38.67 | 0.1599 | 1.0580 |

**Table II: 69 Bus System - PQ Injection.**

| No. of DGs | Objective | DG Location | DG size (KVA) | $f_{Loss\ (kW)}$ | $f_{VP}$ | $f_{VSI}$ |
|---|---|---|---|---|---|---|
| Without DG | | - | - | 225.00 | 3.72 | 1.46 |
| 1 | Loss minimization objective | 61 | 2243.80 | 23.17 | 1.1946 | 1.1180 |
| | Loss minimization, voltage profile improvement and voltage stability | 61 | 2307.24 | 23.30 | 1.1429 | 1.1161 |
| 2 | Loss minimization objective | 61, 17 | 2227.73,614.24 | 7.62 | 0.2222 | 1.0233 |
| | Loss minimization, voltage profile improvement and voltage stability | 61, 18 | 2213.99, 651.06 | 8.29 | 0.1642 | 1.0233 |
| 3 | Loss minimization objective | 61, 17, 50 | 2140.63, 610.53, 883.82 | 5.34 | 0.1935 | 1.0214 |
| | Loss minimization, voltage profile improvement and voltage stability | 61, 18, 50 | 2104.34, 606.01, 901.62 | 5.20 | 0.1638 | 1.0196 |