Optimal placement and sizing of multiple distributed generation units in large-scale distribution systems

Abhishek Gupta[1], Sarfaraz Nawaz[2]
[1,2] *Department of Electrical Engineering, Swami Keshvanand Institute of Technology, Management & Gramothan, Jaipur, India*
doi.org/10.64643/IJIRTV12I11-199543-459

Abstract: The aim of the optimal distributed generations (DG) placement is to provide the best locations and sizes of DGs units to optimize electrical distribution network operation and planning taking into account DG capacity constraints. This paper propose a heuristic technique for optimally determining the location and sizing of different types of distributed generation (DG) units in the distribution network for real power loss reduction. DG type-I and type-II have been considered in the proposed approach. Maximum penetration of type-I DG is considered in a range of 0–50% of total load. The proposed method has been tested on IEEE-69 and 118 bus radial distribution systems. Test results are also compared with other optimization techniques and found that the proposed method is more effective and has higher capability in finding optimum solutions.

I.INTRODUCTION

Distributed generation (DG) devices can be strategically placed in power systems for grid reinforcement, reducing power losses and on–peak operating costs, improving voltage profiles and load factors, differing or eliminating for system upgrades, and improving system integrity, reliability, and efficiency. The aim of the optimal DG placement (OPDG) is to provide the best locations and sizes of DGs to optimize electrical distribution network operation and planning taking into account DG capacity constraints. Several optimization techniques have been presented by researchers in determining the optimal location and size of DG. Such optimization methods can be classified into deterministic methods such as analytical methods and heuristic methods such as Genetic Algorithm (GA), Particle Swarm Optimization (PSO), Artificial Bee Colony (ABC), etc., or into single- and multi-objective, based on the number of objectives. [Kyu-Ho Kim et. al. [1] employed a hybridized method for determining DG size and location in distribution system. The authors combined the GA with fuzzy set theory. M. Gandomkar et.al [2] proposed Hereford Ranch Algorithm (HRA) to determine optimum location and size of DGs. N. Acharya et. al. [3] proposed an analytical method to determine the optimal capacity of DG. Kashem et.al.[4] proposed a deterministic methodology based on the SQP algorithm to identify the optimal location and size of DG in distribution system. Author proposed a multi objective function to minimize real power loss at minimal DG cost. Beromi et.al. [5] used GA technique to determine optimal location of DG for voltage profile improvement and power loss reduction. . S. Kamalinia, et-al [6] presented the solution to optimal DG allocation based on MADM (Multi-Attribute Decision Making) and Genetic algorithm. Gozel et.al [7] formulated loss sensitivity factor to determine the optimum size and location of distributed generation. Mouti and hawary [8] proposed an artificial bee colony (ABC) algorithm for DG placement problem. Safari et.al. [9] used hybrid genetic algorithm and particle swarm optimization technique to determine optimal location and size of DGs. In [10] Particle Swarm Optimization (PSO) technique is used to determine optimal size and location of multi DGs. M. Abbagana et. al. [11] proposed a Differential Evolution technique for the optimum placement and sizing of a DG in a distribution network. Amanifar [12] proposed sensitivity analysis and Particle swarm optimization technique for optimal DG placement, sizing for loss and THD reduction and voltage profile enhancement in distribution system. Shaaban et.al. [13] used analytical technique to determine the optimal size and location of DG in distribution system for power loss reduction and voltage profile improvement. Duong Quoc Hung et. al. [14] proposed an improved analytical (IA) method of multiple distributed generators placement to achieve a high loss reduction in large-scale primary distribution networks.

Different types of Distributed Generators (DGs) are classified as:

Type-I: Deliver only active power (like photovoltaic, micro turbines, fuel cells etc.)

Type-II: Deliver only reactive power (like synchronous compensator, capacitor etc.

Type-III: Deliver both active and reactive power (like synchronous machine)

Type-IV: Deliver active power but consuming reactive power (like induction generators used in wind farms)

Most of the researchers have been used only type-I DG in their algorithm to solve DG placement problem. In the proposed method type-I and type-II DG are used to solve the problem. In this paper, sensitivity analysis method is used to determine optimal location and size of DG units in distribution system. The maximum penetration of type-I DG is considered in a range of 0–50% of total load. The proposed method has been tested on IEEE 69 and IEEE 118 bus test system and results are compared with the various optimization techniques. The rest of the paper is organized as follows: section 2 gives the description of problem formulation. Section 3: gives the solution methodology DG placement problem. Section 4 portrays the simulation results of test distribution systems used in this paper. A brief summary of the obtained results is also included in this section and the conclusion of the paper is summarized in Section 5.

II.PROBLEM FORMULATION

The objective of DG placement problem is to minimize the real power losses of the distribution network through determining the optimal DG sizing and location. The operating constraints of the problem are divided into equality and inequality constraints [20].

For n bus radial distribution system, the problem is formulated as:

$$Minimize\ f = \min\left(W_{DG,\,Loss}\right) \quad (1)$$

Where,

$$W_{DG,Loss} = \sum_{i=1}^{n}\sum_{j=1}^{n}\left[\alpha_{ij}\left(P_iP_j + Q_iQ_j\right) + \beta_{ij}\left(P_jQ_i - P_iQ_j\right)\right] \quad (13)$$

Where,

$$\alpha_{ij} = \frac{R_{ij}}{V_iV_j}\cos\left(\delta_i - \delta_j\right)$$

$$\beta_{ij} = \frac{R_{ij}}{V_iV_j}\sin\left(\delta_i - \delta_j\right)$$

$$Z_{ij} = R_{ij} + X_{ij}$$

Z_{ij} is the impedance of the line between bus i and bus j;

R_{ij} is the resistance of the line between bus i and bus j;

X_{ij} is the reactance of the line between bus i and bus j

V_i is the voltage magnitude at bus i ;

V_j is the voltage magnitude at bus j ;

δ_i is the voltage angle at bus i ;

δ_j is the voltage angle at bus j;

P_i and Q_i is the active and reactive power injection at bus i;

P_j and Q_j is the active and reactive power injection at bus j

Subjected to:

(a) Equality Constraints:

The power flow equations must be satisfied as:

$$P_i = P_{DGi} - P_{Di} = V_i\sum_{j=1}^{n}V_j\left(G_{ij}\cos\left(\delta_i - \delta_j\right) + B_{ij}\sin\left(\delta_i - \delta_j\right)\right) \quad (2)$$

$$Q_i = Q_{DGi} - Q_{Di} = V_i\sum_{j=1}^{n}V_j\left(G_{ij}\sin\left(\delta_i - \delta_j\right) - B_{ij}\cos\left(\delta_i - \delta_j\right)\right) \quad (3)$$

Where, P_{DGi} and Q_{DGi} are distributed power generations at bus i. P_{Di} and Q_{Di} are the loads at bus i. G_{ij} is the conductance of the line between bus i and bus j and B_{ij} is the susceptance of the line between bus i and bus j.

(b) Inequality Constraints:

(i) Power generation limit must be satisfied as

$$P_{DGi}^{min} \le P_{DGi} \le P_{DGi}^{max}$$

$$Q_{DGi}^{min} \le Q_{DGi} \le Q_{DGi}^{max}$$

(ii) Bus voltage limits $V_{min} \le V_i \le V_{max}$

(iii) Line current constraints $I_i \le I_i^{rated}$

Where I_i^{rated} *is current permissible for branch i within safe limit of temperature.*

III. SOLUTION METHODOLOGY

To solve the DG allocation and sizing problem, heuristic sensitivity technique is used. The sensitivity constant to determine the size and location of type-I DG for each bus is given by

$$sk_i = \frac{1}{S} + \frac{Pdgloss\ (i)}{Prealloss} \quad (4)$$

The sensitivity constant to determine the size and location of type-II DG for each bus is given by

$$sk_i = \frac{1}{S} + \frac{Pdgimgloss\ (i)}{Pimgloss} \quad (5)$$

Where,

$$S = \sum_{i=1}^{n} KVA_L(i) * V(i)$$

$KVA_L(i)$ is the load at i^{th} bus in kVA.
$V(i)$ is the voltage at i^{th} bus in kV.
P_{dgloss} is the real power loss after DG placement at i^{th} bus.
$P_{realloss}$ is the real power loss of the system without DG placement.
$P_{dgimgloss}$ is the reactive power loss after DG placement at i^{th} bus.
$P_{imgloss}$ is the reactive power loss of the system without DG placement.
Sensitivity constant (sk) is evaluated at each bus, firstly using the values obtained from the base case power flow. The buses are ranked in descending order of the values of their sensitivity constant to form a priority list. The top-ranked buses in the priority list are the first to be selected for alternatives location.

Computational procedure:
Step 1: Run load flow program for base case.
Step 2: Calculate the sensitivity constant using Eq. (4) or (5) of each bus and rank the sensitivity in descending order and form priority list.
Step 3: Select the bus which has highest priority and place DG at that bus.
Step 4: Now change the size of DG in ''small'' step and calculate real or reactive power loss for each size by running load flow program.
Step 5: Store the size of DG that gives the minimum loss.
Step 6: Repeat Step 3 to 5 to find more location of DGs.
Step 7: Place the DG of obtained size at optimal location and once again perform load flow

IV. SIMULATION RESULTS

To illustrate the effectiveness of the proposed method it is tested on IEEE 69 and IEEE 118 bus radial distribution system. The proposed method is implemented using MATLAB 10 software running on a computer with Intel_ Core_ i3 CPU @ 2.27 GHz and 4 GB of RAM.
For each system three cases are considered.
Case I: Only type-I DGs is placed

Case-II: Only type-II DGs is placed

Case-III: Simultaneous placement of type-I and type-II DGs

4.1 Test system-I (IEEE 69 bus system)
The IEEE 69 bus radial distribution system [15] has a total load of 3.802 MW and 2.694 MVAr. The system has real power loss of 225 kW and minimum bus voltage is 0.9092 pu.

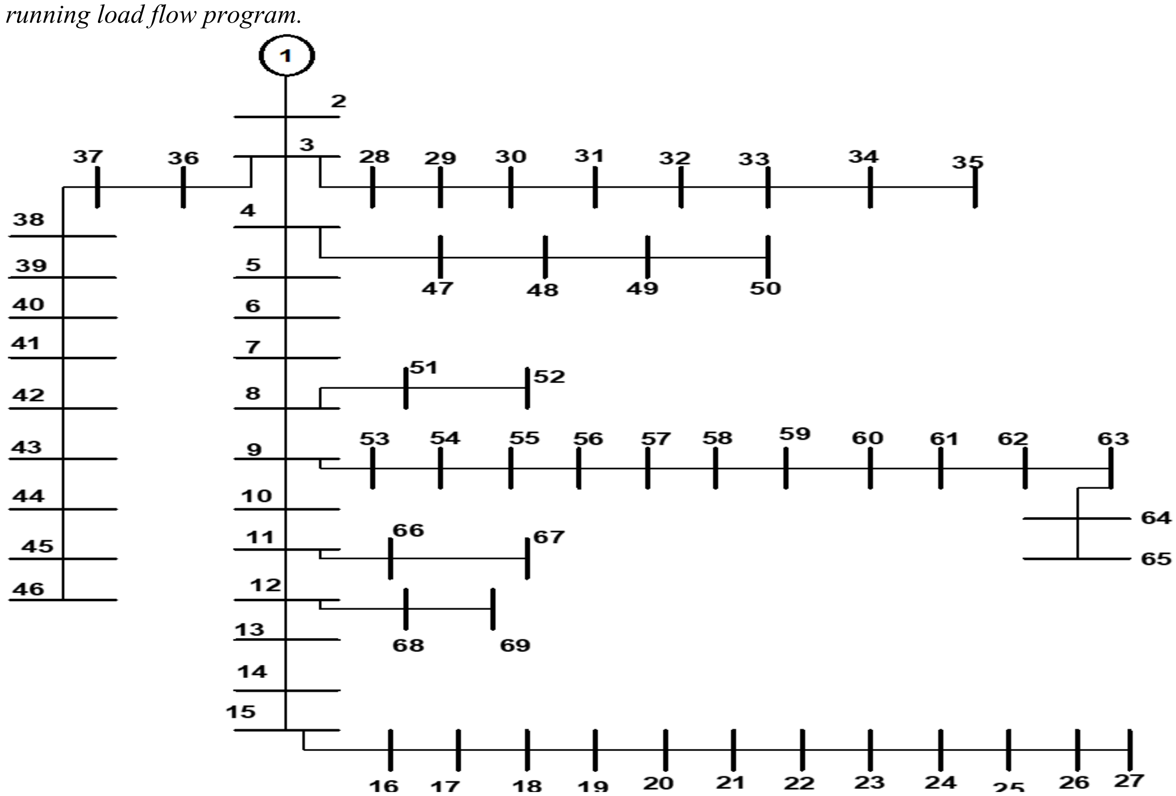

Fig.1 IEEE 69 bus distribution system

Case –I: Only type-I DGs is placed

The proposed technique is applied on 69 bus system. The optimal location and size of DG type-I is shown in table 1. 50% DG penetration is used here. It is observed from table 1 that after DG placement of total size 1750 kW at specified location the real power loss is reduced to 78.3 kW it accounts for 65.2% of loss reduction and minimum bus voltage is improved to 0.97 pu.

Table 1: Simulation results of DG type-I on 69 bus system.

Bus Location (Size in kW)	Real Power Loss	Bus Voltage	% loss reduction
21 (250) 61 (950) 64 (550)	78.3 kW	0.9704	65.2 %

Case –II: Only type-II DGs is placed

The DG type –II (capacitor) is used for placement. It is observed from table 2, that optimal location and size of DG type-II is bus 61 and 1050kVAr. This will reduce the power loss to 155.02 kW and enhanced the bus voltage to 0.9265 pu.

Table 2: Simulation results of DG type-II on 69 bus system.

Bus Location (Size in kVAr)	Real Power Loss	Bus Voltage	% loss reduction
61 (1050)	155.02 kW	0.9265	31.1 %

Case –III: Simultaneous placement of type-I and type-II DGs

The obtained results for simultaneous placement of a type-I and type-II DG are shown in table 3. The real power loss is now 19.60 kW i.e. 91.3 % loss reduction. The minimum bus voltage is also enhanced to 0.9815 pu.

Table 3: Simulation results of Simultaneous placement of type-I and type-II DGs on 69 bus system.

DG Type	Type-I	Type-II
Optimum Location	21 (250) 61 (950) 64 (550)	61 (1050)
Total Size	1750 kW	1050kVAr
Power Loss	19.60 kW	
% Loss Reduction	91.28%	
Min. bus Voltage	0.9815 pu	

Table 4: Comparison of results of Simultaneous placement of type-I and type-II DGs on 69 bus system

	PSO [16]	Proposed
Total DG Type-I size (kW)	1828	1750
Total DG Type-II size (kVAr)	1300	1050
Power Loss (kW)	23.17	19.60
% Loss reduction	89.7%	91.28%
Minimum bus Voltage	0.9724	0.9815

In table 4, the results of proposed method for 69 bus system are compared with results of PSO [16] technique. It is seen from table, that the proposed method gives more loss reduction on less DG (type-I & II) size. The minimum bus voltage is also enhanced in proposed method. Figure 2 shows the comparison of real power loss for base case, after DG type-I placement, after DG type-II placement and after simultaneous placement of DG type-I and II. The comparison of bus voltages are shown in figure 3.

Table 5: Comparison of results of placement of type-I DGs on 69 bus system

Method	Total DG size (kW)	Power Loss (kW)	% loss reduction	Vmin. (pu)
GA [17]	2998	89	60.44	0.993
PSO [16]	1808	83.36	62.95	0.9679
SA [18]	2181	83.31	62.97	0.9811
Analytical [3]	1810	81.44	63.8	-
BFO [19]	2025	84.2	62.5	0.9875
MBFO [19]	1880	83.4	62.9	0.9797
Proposed	1750	78.3	65.2	0.971

The simulation results for DG type-I placement are compared with various optimization techniques like genetic algorithm (GA), particle swarm optimization (PSO), simulated annealing (SA), analytical method, Bacterial Foraging Optimization algorithm (BFO) etc in table 5. From the table it is observed that the percentage loss reduction by proposed method is least from all other methods. The size of DG unit is also less as compared to other techniques.

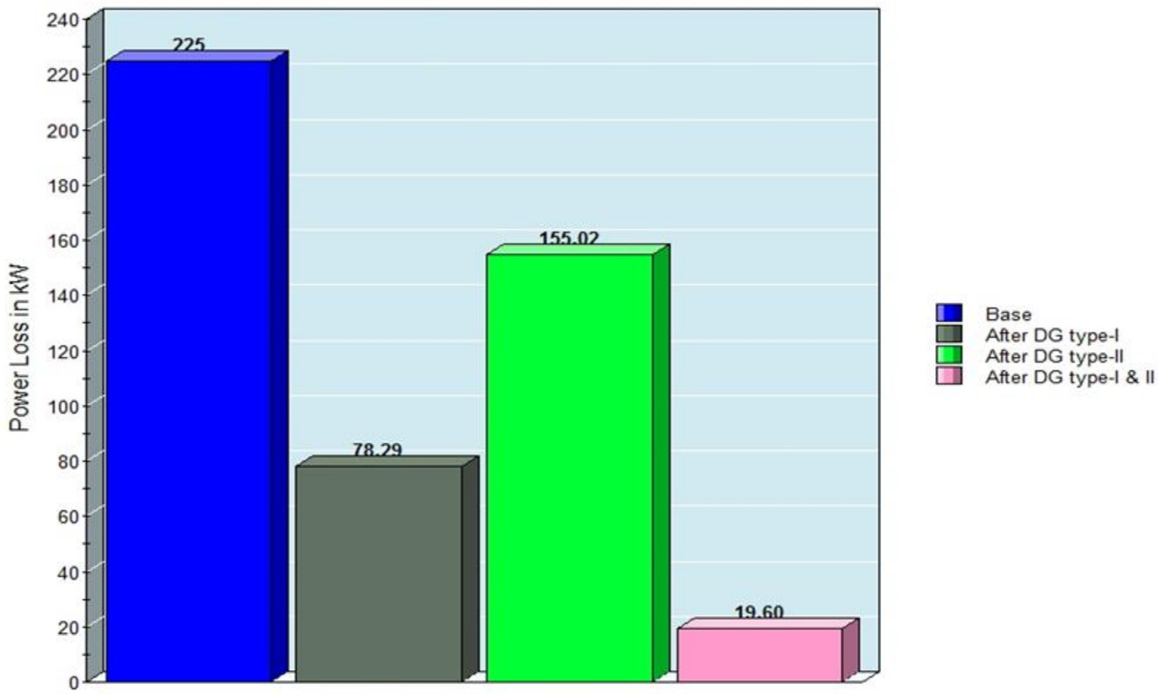

Fig. 2 Comparison of power loss for 69 bus system

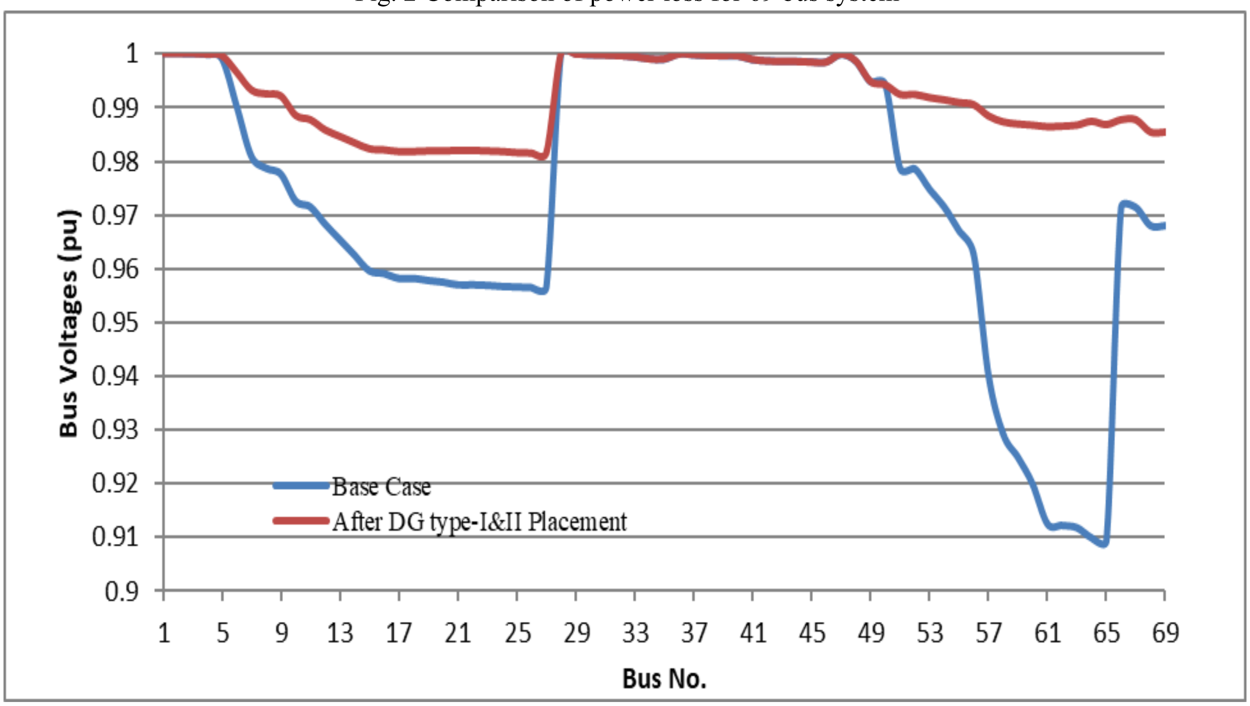

Fig. 3 Comparison of bus voltages before & after DG placement for 69 bus system

4.2 Test system-II (IEEE 118 bus system)

Second test system is a 11 kV, 118 bus radial distribution system [22]. The total load is 22709.7 kW and 17041.1 kVAR. The base case real power loss and minimum bus voltage are 1245 kW and 0.8737 pu respectively.

Case –I: Only type-I DGs is placed

For type-I DGs optimal location for 118 bus system are found at 51 (1680 kW), 74 (1820 kW), 111 (1760 kW). The reduction in real power loss is 42.9 %. From the table 6, it is seen that minimum bus voltage is also improved to 0.939 pu. The maximum size of DG type-I at each bus has been fix to 2 MW.

Table 6: Simulation results of DG type-I on 118 bus system.

Bus number (Size in kW) (0-2000kW)	Real Power Loss (kW)	Bus Voltage (pu)	% loss reduction
51 (1680) 74 (1820) 111 (1760)	711	0.93	42.9

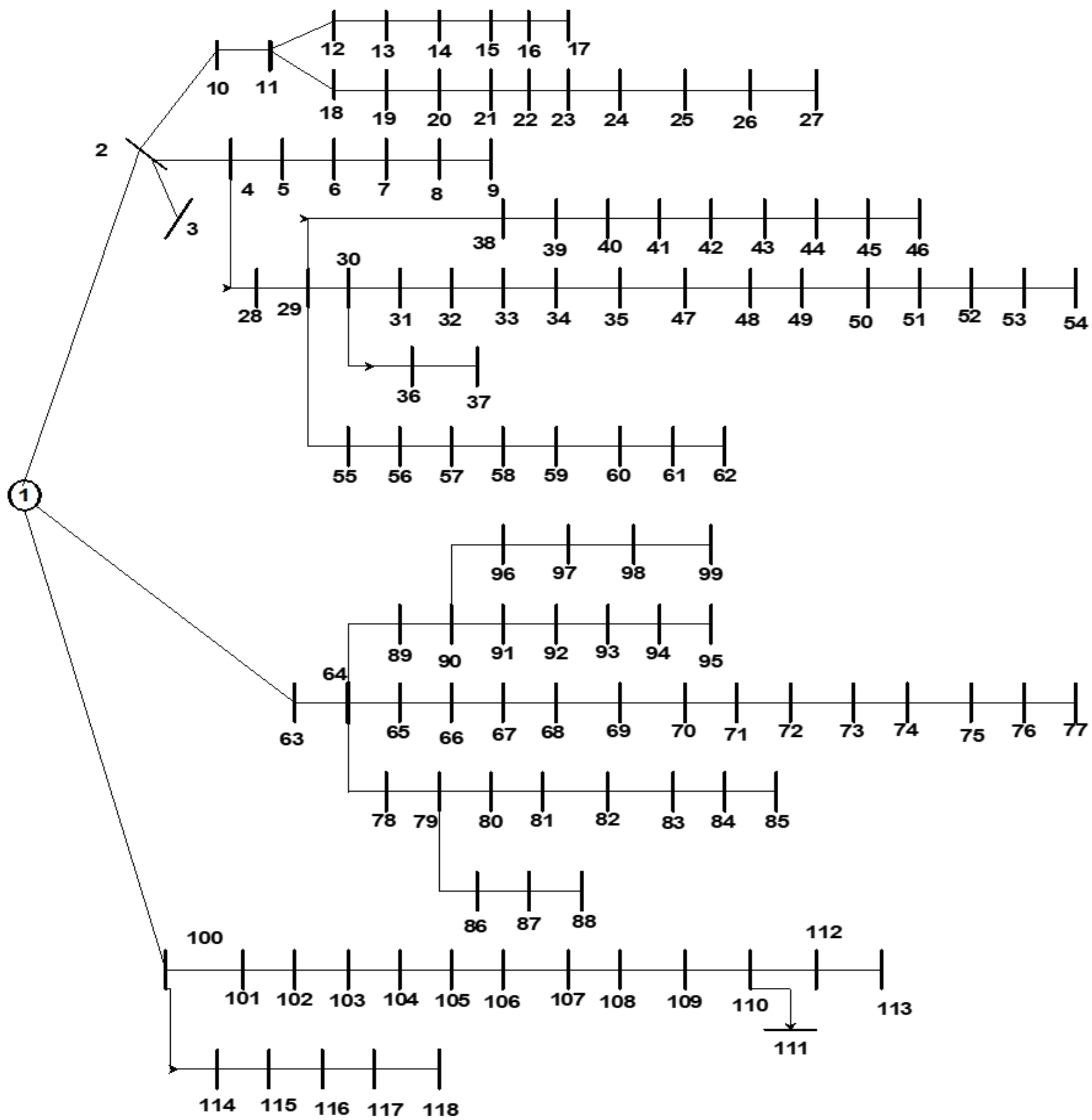

Fig.4 IEEE 118 bus distribution system

Case –II: Only type-II DG is placed

The optimum DG size and location for type-II DG unit is obtained as 2500 kVAr at bus 74. This accounts to 29.2 % power loss reduction. Minimum bus voltage is also improved to 0.905 pu.

Table 7: Simulation results of DG type-II on 118 bus system.

Bus Location (Size in kVAr)	Real Power Loss (kW)	Bus Voltage (pu)	% loss reduction
74 (2500)	881.03	0.9053	29.2 %

Case –III: Simultaneous placement of type-I and type-II DGs

The results obtained from simultaneous placement of a type-I and type-II DG for 118 bus system is shown in table 8. The real power loss is reduced to 510.67 kW. It accounts to 59 % loss reduction. The minimum bus voltage is also enhanced to 0.94 pu.

Table 8: Simulation results of Simultaneous placement of type-I and type-II DGs on 118 bus system.

DG Type	Type-I	Type-II
Optimum Location	51 (1680) 74 (1820) 111 (1760)	74 (2500)
Total Size	5260 kW	2500kVAr
Power Loss	510.67 kW	
% Loss Reduction	59%	
Min. bus Voltage	0.940 pu	

Figure 5 shows the comparison of real power loss for base case, after DG type-I placement, after DG type-II placement and after simultaneous placement of DG type-I and II. The comparison of bus voltages for 118 bus system are shown in figure 6.

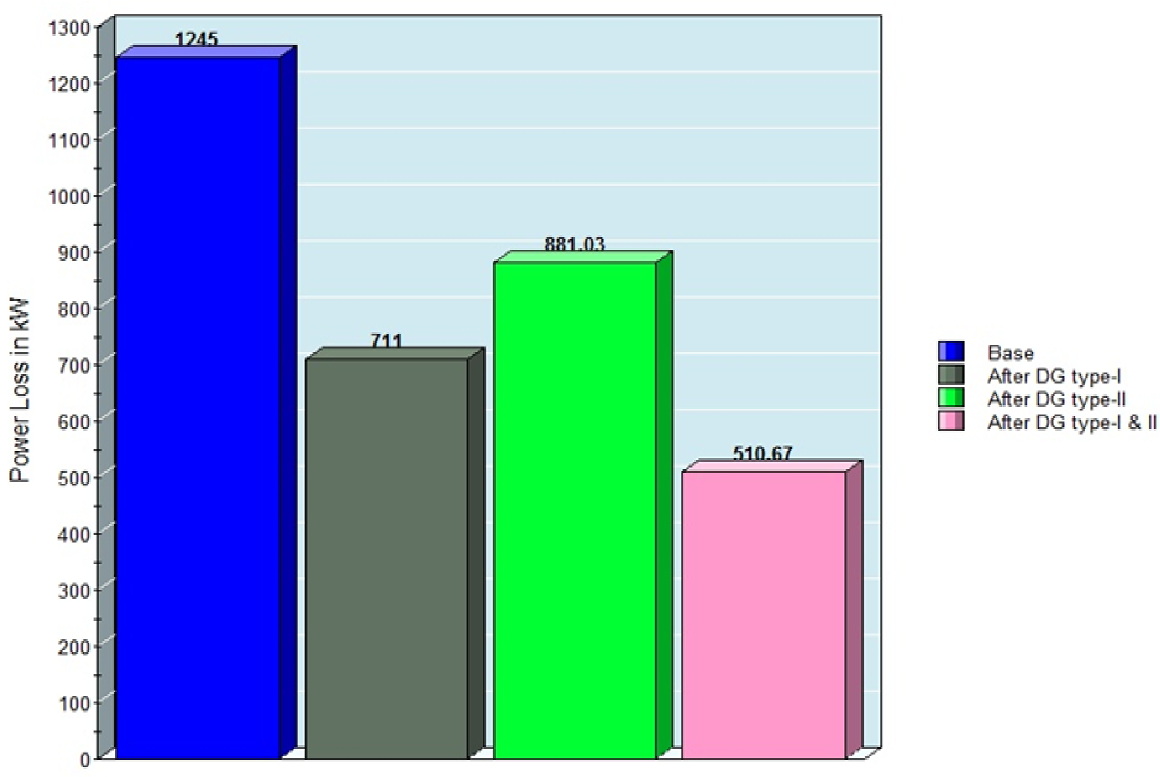

Fig. 5 Comparison of power loss for 118 bus system

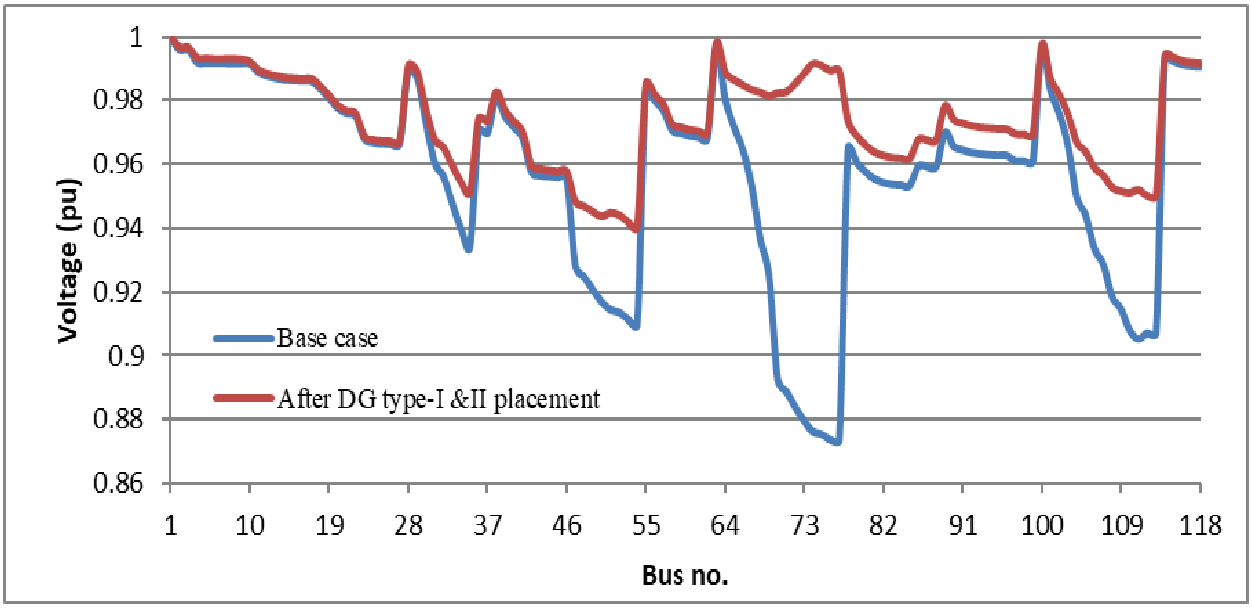

Fig. 6 Comparison of bus voltages before & after DG placement for 118 bus system

V. CONCLUSION

In this paper, heuristic sensitivity technique has been presented to solve the DG placement problem in radial distribution system. The optimal location and size of DG units has been determined in order to minimize real power losses and to enhance the voltage profile. Two types of DG units (type-I and type-II) are used to solve the problem. The method is implemented on two test system and simulation results have shown better performance and effectiveness of the proposed method. The obtained results produce better results when compared with various optimization technique.

ACKNOWLEDGEMENT

The authors would like to express their sincere gratitude to Swami Keshavanand Institute of Technology, Management & Gramothan (SKIT), Jaipur for providing the necessary academic environment, resources, and continuous support to carry out this research work successfully.

REFERENCES

[1] Kyu-Ho Kim, Yu-Jeong Lee, Sang-Bong Rhee, Sang-Kuen Lee and Seok-Ku You, "Dispersed generator placement using fuzzy-GA in distribution systems," Power Engineering Society Summer Meeting, 2002 IEEE, vol.3, pp.1148,1153, Jul. 2002

[2] M. Gandomkar, M. Vakilian and M. Ehsan, "Optimal distributed generation allocation in distribution network using Hereford ranch algorithm," Electrical Machines and Systems, 2005. ICEMS 2005. Proceedings of the Eighth International Conference on, Vol.2, No. 1, pp.916-918, 2005.

[3] N. Acharya, P. Mahat, N. Mithulananthan, "An Analytical approach for DG allocation in Primary Distribution Network," Electrical Power and Energy Systems, Elsevier, Vol. 28, pp. 669-678, 2006.

[4] A. D. T. Le, M. A. Kashem, M. Negnevitsky and G. Ledwich, "Optimal distributed generation parameters for reducing losses with economic consideration," Power Engineering Society General Meeting IEEE, pp. 1-8, 2007.

[5] Y. Alinejad-Beromi, M. Sedighizadeh, M. R. Bayat and M. E. Khodayar, "Using genetic algorithm for distributed generation allocation to reduce losses and improve voltage profile," Universities Power Engineering Conference, UPEC 2007. 42nd International, pp.954-959, 2007.

[6] S. Kamalinia, "A combination of MADM and genetic algorithm for optimal DG allocation in power systems", Universities Power Engineering Conference, 2007. UPEC 2007. 42nd International, Sept. 2007

[7] T. Gozel and M. H. Hocaoglu, “An analytical method for sizing and siting of distributed generators in radial systems”, Electrical Power and Energy Systems -Elsevier, Vol. 79, No. 1, pp. 912-918, 2009.

[8] F. S. Abu-Mouti and M. E. El- Hawary, “Heuristic curve -fitted technique for distributed generation optimization in radial distribution feeder systems”, IET Generation, Transmission and Distribution”, Vol. 5, No. 2, pp. 172 -180, 2009.

[9] A. Safari, R. Jahani, H. A. Shayanfar, J. Olamae, “Optimal DG allocation in distribution network”, International Journal of Electrical and Electronics Engineering, Vol. 4, No. 8, pp. 550-553, 2010.

[10] Wichit Krueasu, Weerakorn Ongsakul “Optimal Placement of Distributed Generation Using Particle Swarm Optimization” 2010

[11] M. Abbagana, G. A. Bakare, and I. Mustapha “Optimal Placement and Sizing of a Distributed Generator in a Power Distribution System Using Differential Evolution” Proceedings of the 1st International Technology, Education and Environment Conference African Society for Scientific Research (ASSR) 2010

[12] O. Amanifar, "Optimal distributed generation placement and sizing for loss and THD reduction and voltage profile improvement in distribution systems using particle swarm optimization and sensitivity analysis” electrical Power Distribution Networks (EPDC), 2011 16th Conference on , Vol. 8, No. 3, pp. 1, 2011.

[13] M. Shaaban, J. O. Petinrin, “Sizing and siting of DG in distribution system for voltage profile improvement and loss reduction”, International Journal of Smart Grid and Clean Energy, Vol. 8, No.1, pp. 1-7, 2013.

[14] Duong Quoc Hung, Nadarajah Mithulananthan “Multiple Distributed Generator Placement in Primary Distribution Networks for Loss Reduction” IEEE Transactions on Industrial Electronics, Vol. 60, no. 4, April 2013.

[15] J. S. Savier and D. Das, “Impact of network reconfiguration on loss allocation of radial distribution systems,” IEEE Trans. Power. Del., vol. 2, no. 4, pp. 2473-2480, Oct 2007.

[16] Satish Kansal, Vishal Kumar, Barjeev Tyagi, “Optimal placement of different type of DG sources in distribution networks” Electrical Power and Energy Systems –Elsevier vol. 53, pp 752–760, 2013

[17] Moradi MH, Abedini M. A combination of genetic algorithm and particle swarm optimization for optimal DG location and sizing in distribution systems. Electrical Power Energy System 34:66–74, 2012

[18] Satish Kumar Injeti, N. Prema Kumar, “A novel approach to identify optimal access point and capacity of multiple DGs in a small, medium and large scale radial distribution systems” Electrical Power Energy System 45: 142-151, 2013.

[19] S. Devi, M. Geethanjali, “Application of Modified Bacterial Foraging Optimization algorithm for optimal placement and sizing of Distributed Generation” Expert Systems with Applications vol.41, pp 2772–2781,2014

[20] Tandon, A., & Nawaz, S. (2024). Positioning and sizing of PV-based DG and capacitor in realistic distribution network and verification through ETAP simulation. Electric Power Components and Systems, 52(2), 189-218.