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Optimal Placement of DG in Distribution network for Power loss minimization using NLP & PLS Technique

P. Vijay Babu[a] & S.P. Singh[b]*

[a,b] *Department of Electrical Engineering, IIT (BHU) Varanasi, Varanasi, UP,221005, India*

Abstract

A novel application of General Algebraic Modelling System (GAMS) software has been reported in this paper to determine the load flow solution for both radial and mesh distribution network. With interfacing of GAMS and MATLAB, optimal sitting and sizing of Distributed Generator (DG) in radial/mesh distribution systems is efficiently done in order to reduce power loss and improvement of voltage profile in distribution systems.
The main contributions of the paper are as follows:

(i) Load flow solution by GAMS software for both radial and mesh distribution networks.
(ii) Planning of optimal sitting and sizing of DG has been carried out in two phases. In first phase, optimal locations of DG based on the Power Loss Sensitivity (PLS) and in second phase, optimal size of DG has been determined by CONOPT solver of GAMS, solves Non-Linear programming (NLP).
(iii) Two types of DGs have been considered for analysis i.e. Type 1 (DG operating at unity power factor) and Type 3 (DG operating at lagging power factor).

The results are obtained on IEEE 33-bus and IEEE 69-bus radial distribution systems and also compared with other existing methods. The test results demonstrate that the proposed method produced superior results in respect of loss reduction, improvement in voltage profile and computational time.

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Keywords: Radial/mesh distribution system; GAMS; Distributed Generator.

* Corresponding author. Tel.: +91 7052306434
E-mail address: spsingh.eee@itbhu.ac.in

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1. Introduction

Distribution networks are either radial or weakly meshed mostly, due to high R/X ratio causes more power losses and voltage drop. Large amount of total power losses in power system occurs in Distribution system. Power loss minimization plays a crucial role for economic operation and energy cost reduction. There are many ways to reduce the losses as like capacitor placement, Distributed Generation placement, load management and network reconfiguration. A thorough description of the state-of the- art models and optimization methods applied to the optimal DG placement problem, analyzing and classifying current and future research trends was presented in [1].

Nomenclature

n	total number of nodes (buses)
br	total number of branches
V_i, V_j	voltage at *i*th node and *j*th node respectively
R_{ij}, X_{ij}	resistance and reactance of branch connected between *i*th node and *j*th node respectively
δ_i, δ_j	voltage angle at *i*th node and *j*th node respectively
Pl_{ij}, Ql_{ij}	active and reactive power loss in branch connected between *i*th node and *j*th node respectively
S_{ij}	apparent power flow in a branch connected between *i*th node and *j*th node
Pg_i, Qg_i	active and reactive power generation at *i*th node respectively
Pd_i, Qd_i	active and reactive power demand at *i*th node respectively
$Pg_i^{\max}, Qg_i^{\max}$	maximum generation limit of active and reactive power at *i*th node respectively
$Pg_i^{\min}, Qg_i^{\min}$	minimum generation limit of active and reactive power at *i*th node respectively
$V_i^{\max}, \delta_i^{\max}$	maximum limit of voltage and voltage angle at *i*th node respectively
$V_i^{\min}, \delta_i^{\min}$	minimum limit of voltage and voltage angle at *i*th node respectively
$S_{ij}^{\max}$	maximum apparent power flow limit in a branch connected between *i*th node and *j*th node
P_j, Q_j	active and reactive power injection at *j*th node respectively
$P_{loss}, Q_{loss}, S_{loss},$	active, reactive and apparent power loss in the system
Pdg_j, Qdg_j	DG active and reactive power injection at *j*th node respectively
$Pdg_i^{\max}, Qdg_i^{\max}$	maximum limit of DG active and reactive power demand at *i*th node respectively
$Pdg_i^{\min}, Qdg_i^{\min}$	minimum limit of DG active and reactive power demand at *i*th node respectively
$pfdg_i^{up}, pfdg_i^{lo}$	upper and lower limit of power factor of DG at *i*th node

Several techniques have been recently proposed for the optimal placement of DG in a distribution system for power loss minimization. These techniques involves analytical method [2-7], Genetic Algorithm (GA) [8, 9], Particle Swarm Optimization (PSO) [10,11,], Harmony Search Algorithm (HSA) [12], Simulated Annealing (SA) [13].

An analytical approach based on the exact power loss formula for optimal allocation of single DG was presented in [2]. In [3,4] for minimization of real power loss in a primary distribution network, proposed an improved analytical (IA) expressions to determine the optimal size of different types of distributed generator at optimal power factor for both single and multiple DG allocation in a distribution systems. An analytical approach has been presented in [5] to identify the location to optimally place single DG with unity power factor in radial as well as meshed networks to minimize losses. However, in this approach, the optimal sizing is not considered. In [6] a new analytical method (AM) for optimal sitting and sizes of multiple DGs to minimize the both real and reactive power losses. However, this method does not provide computation time. A novel power flow solution method and also analytical method for optimal allocation of multiple DGs in distribution system for loss reduction was proposed in [7]. A multi-objective mixed integer programming has been solved by GA was proposed in [8] considering the uncertainty and variability associated with the intermitted nature of renewable energy resources and also loads. Optimal location of DG based on exact loss formula and optimal sizing of DG by GA was proposed in [9] to minimize power losses. Combination of GA and PSO for optimal location and capacity of DG, considering multi- objective constraints like voltage stability, losses and improved voltage regulations has been proposed in [10]. An approach for the multiple-DG planning was proposed in [11], by using constriction factor based PSO. Minimization of power loss in a distribution system by considering simultaneously network reconfiguration and DGs placement based on Harmony Search Algorithm (HSA) has been presented in [12]. Simulated Annealing (SA) was used in [13] for optimal size of DGs and power loss sensitivity factor (LSF) for optimal sitting. Modified teaching learning based optimization (MTLBO) algorithm was applied to determine optimal location and size of DG in the distribution system in [14]. Comparison of different loss sensitivity methods for single DG placement has been presented in [15]. However, this method does not considered the optimal power factor of DG. "2/3 (Thumb) rule" was developed in [16] for optimal DG placement with uniformly distributed load. However, this method may not be effective for meshed system and non-uniform loading. A mixed-integer linear programming approach was proposed in [17] to solve the problem of optimal type, size and allocation of DGs. In [18], a direct search approach was proposed for DG allocation in radial distribution networks to reduce power loss. A novel hybrid combination of particle swarm optimisation (PSO), and gravitational search algorithm (GSA) was introduced in [19] to solve the multi-objective index-based approach for determining the optimal placement and size of multi-DG units in distribution system for power loss reduction. However, search based techniques depends on tuning parameters. If these parameters are not carefully chosen, these techniques lead to a sub-optimal solution. In [20] a two phase algorithm was proposed, in first phase optimal location of DG and next phase optimal DG size were determined respectively.

However, many methods, considered the minimization of real power loss but not reactive power loss. In this paper, minimization of both real and reactive power loss is considered. Proposed a new load flow solution by GAMS software [24] can be easily applied for both radial and mesh distribution networks and also proposed a new algorithm for optimal placement of DG, which is carried out in two phases. In first phase, optimal location of DG is determined based on the Power Loss Sensitivity (PLS) and in second phase, optimal size of DG has been obtained by CONOPT solver of GAMS, solves Non-Linear programming (NLP).

The remainder of this paper is structured as follows: section 2 describes about the General Algebraic Modeling System (GAMS) software and its interface with MATLAB, proposed load flow solution and power loss sensitivity (PLS). Section 3 presents algorithm for optimal placement of DGs and Flow chart of proposed method. Section 4 portrays the case studies results and discussions and along with some observations. Finally, Conclusion is presented in section 5.

2. Problem formulation

2.1. GAMS software and interfacing of GAMS and MATLAB

General Algebraic Modeling System (GAMS) is a high-level algebraic modeling system for large scale optimization. It is specifically designed for modeling linear, nonlinear and mixed integer optimization problems. GAMS is a combination of a modeling system and a library of solvers and has its own programming language syntax. It allows the user to write any optimization problem in the syntax of GAMS as shown in Fig.1. Any optimization problem can be written in GAMS syntax, which is independent of the type of solver to be used to solve it. This allows the user to solve and test a given optimization problem using several solvers from the GAMS solvers library. Thus, if user wants to utilize different solver, no need to remodel the optimization problem. Hence user can solve one model with several solvers and compare algorithms based on their results. GAMS solver can capable to solve up to millions of variables in a given optimization problem. First and most important thing is modeling, in which formation of an accurate GAMS model for an optimization problem is done, and then selects an appropriate GAMS solver to solve the model. Interfacing of GAMS and MATLAB [25] is also necessary. It can be easily done as shown in Fig. 2.

- If user have a simulation on MATLAB and part of his/her MATLAB code need to solve a complex optimization problem
- For better view of results i.e. in Matrix form or plot

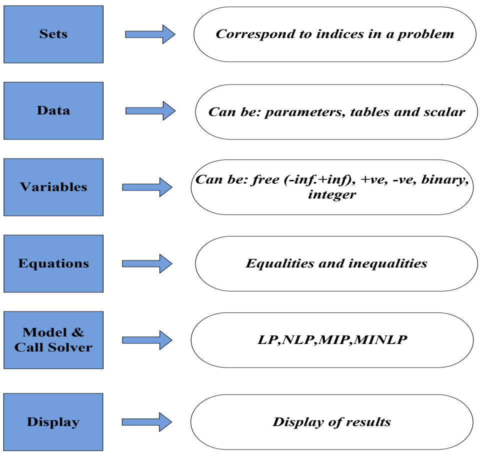

Fig. 1. Basic components of GAMS model

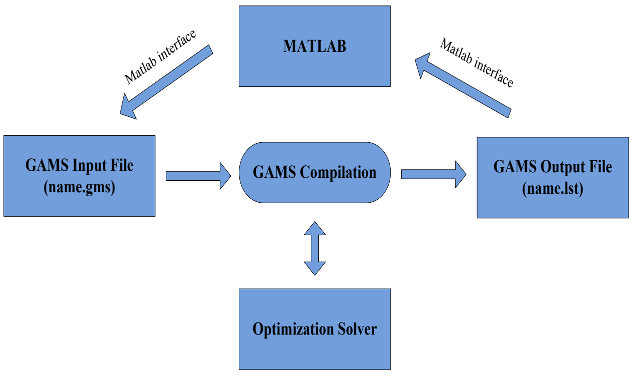

Fig. 2. Structure of GAMS and MATLAB interface

2.2. Load flow solution by GAMS software

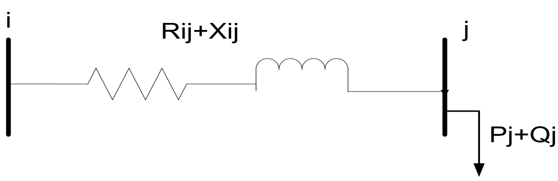

Fig. 3. Equivalent of simple radial distribution system

A Simple radial distribution system is given in Fig. 3. Minimization of both real and reactive power losses in the distribution system is the objective function is given in equation (1),

$$F = \sum_{ij=1}^{br} Pl_{ij} + \sum_{ij=1}^{br} Ql_{ij} \tag{1}$$

Subjected to the following constraints

(i) Power flow Equations: The real and reactive power balance equations are taken as load flow constraints is given in equation (2-3) at the node i respectively

$$P_i = Pg_i - Pd_i = \sum_{i=1}^{n} V_i V_j \left[G_{ij} \cos\left(\delta_i - \delta_j\right) + B_{ij} \sin\left(\delta_i - \delta_j\right) \right] \tag{2}$$

$$Q_i = Qg_i - Qd_i = \sum_{i=1}^{n} V_i V_j \left[G_{ij} \sin\left(\delta_i - \delta_j\right) - B_{ij} \cos\left(\delta_i - \delta_j\right) \right] \tag{3}$$

Where $\forall i = 1,2,........n \; and \; ij = 1,2,.......br$

(ii) Limits of voltage: This includes minimum and maximum value limits of voltage at node the node i

$$V_i^{\min} \le V_i \le V_i^{\max}; \forall i = 1,2,......n \tag{4}$$

(iii) Limits of voltage angle: This includes minimum and maximum value limits of voltage angle at node the node i

$$\delta_i^{\min} \le \delta_i \le \delta_i^{\max}; \forall i = 1,2,......n \tag{5}$$

(iv) Limits of Capacity of Distribution substation: This includes real and reactive power generation limit at root node as represented in equation (6) & (7) respectively.

$$0 \le Pg_i \le Pg_i^{\max}; i = 1(Root\ node) \tag{6}$$

$$Qg_i^{\min} \le Qg_i \le Qg_i^{\max}; i = 1(Root\ node) \tag{7}$$

The constraints from equation (1) to equation (7) are needed to write in the form of GAMS syntax in the model to solve the load flow solution of a distribution system.

(v) Limits of Capacity of DG at optimal location: This includes real and reactive DG power generation limit at node i other than root node can be represented as equation (6) & (7) respectively

$$Pdg_i^{\min} \le Pdg_i \le Pdg_i^{\max}; i \ne 1(Root\ node) \tag{10}$$

$$Qdg_i^{\min} \le Qdg_i \le Qdg_i^{\max}; i \ne 1(Root\ node) \tag{11}$$

(vi) Limits of power factor of DG at optimal location:

$$pfdg_i^{lo} \le pfdg_i \le pfdg_i^{up}; i \ne 1(Root\ node) \tag{12}$$

(vii) Limits of branch power flow: This includes the maximum power flow in a branch ij should not exceed the thermal limit of that branch

$$S_{ij} \le S_{ij}^{\max}; ij = 1,2,.......br \tag{13}$$

In addition to above constraints, equation (10) to equation (13) are included in the GAMS model for determining optimal DG size after selection of optimal location by using PLS technique, which is explained in section 2.3.

2.3. Power loss sensitivity (PLS)

In this phase, Power Loss Sensitivity (PLS) is to determine the potential nodes for DG placement [15, 20]. Thus reduce search space and computational burden.
PLS of each node differentiate with respect to active power injection is

$$\left.\begin{aligned} \frac{\partial Sloss}{\partial P_j} &= \frac{\partial Ploss}{\partial P_j} + j\frac{\partial Qloss}{\partial P_j} \\ \frac{\partial Sloss}{\partial P_j} &= \frac{2*P_j*R_{ij}}{V_j^2} + j\frac{2*P_j*X_{ij}}{V_j^2} \end{aligned}\right\} \tag{14}$$

PLS of each node differentiate with respect to reactive power injection is

$$\left.\begin{aligned} \frac{\partial Sloss}{\partial Q_j} &= \frac{\partial Ploss}{\partial Q_j} + j\frac{\partial Qloss}{\partial Q_j} \\ \frac{\partial Sloss}{\partial Q_j} &= \frac{2*Q_j*R_{ij}}{V_j^2} + j\frac{2*Q_j*X_{ij}}{V_j^2} \end{aligned}\right\} \tag{15}$$

Combined PLS at each node can be calculated as

$$Combined\ PLS = \begin{vmatrix} \frac{\partial Ploss}{\partial P_j} & \frac{\partial Qloss}{\partial P_j} \\ \frac{\partial Ploss}{\partial Q_j} & \frac{\partial Qloss}{\partial Q_j} \end{vmatrix} \tag{16}$$

$$Combined\ PLS = \begin{vmatrix} \frac{2*P_j*R_{ij}}{V_j^2} & \frac{2*P_j*X_{ij}}{V_j^2} \\ \frac{2*Q_j*R_{ij}}{V_j^2} & \frac{2*Q_j*X_{ij}}{V_j^2} \end{vmatrix} \tag{17}$$

Node with higher Combined PLS value is selected as potential nodes for DG placement. The algorithmic steps as discussed in the section 2 are given in section 3 and the flow chart of the proposed method as explained in the previous sections is shown in Fig. 4.

3. Algorithm for optimal placement of DG

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

Step 1: Run the load flow program and obtain the base case total power losses.
Step 2: Obtain the Power Loss Sensitivity (PLS) at each node. Select the node having highest PLS factor as optimal DG location.
Step 3: Transfer control parameters to GAMS by interfacing MATLAB with GAMS.
Step 4: Solve the optimal DG size using CONOPT solver of GAMS in GAMS software.
Step 5: Transfer all variables from GAMS to MATLAB.

Step 6:Print the results.

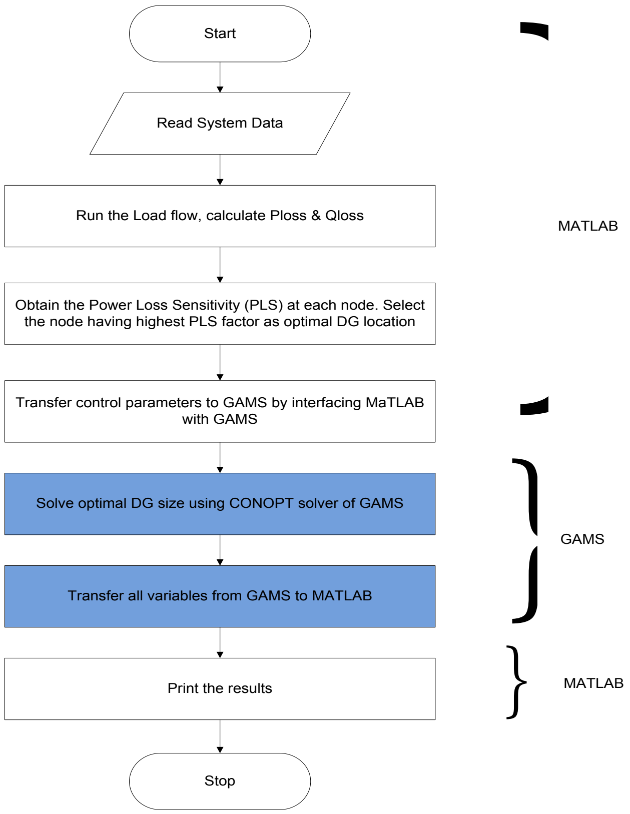

Fig. 4. Flow chart of proposed method

4. Results and Discussions

To demonstrate the effectiveness of the Proposed Load flow solution by GAMS optimization tool has been tested on several test systems, and then planning of optimal sitting and sizing of DG has been determined.

4.1. Validation of Proposed Load flow Solution by GAMS

Proposed Load flow solution is tested on both radial/ mesh distribution systems, which include 10-bus system, 12-bus system, 15-bus system, 33-bus system, 69-bus system, and 85-bus system. The 33-bus, 69-bus radial distribution system and 33-bus mesh distribution system load flow results are presented in this paper.

4.1.1. 33-bus radial distribution System

The first case study is a 100 kVA, 12.66 kV, radial distribution system; it has 33 buses and 32 branches. The total load on 33-bus radial distribution system is 3.715+j*2.3 MVA [22]. The voltage profile, total active and reactive power losses obtained by Proposed Load flow method is given in Table.1 and also compared with existing direct approach method. Minimum voltage is 0.90377 p.u occurred at bus 18 and total active and reactive power losses are 211 kW and 143.13 kVAR respectively. From results it can be observed that proposed load flow solution gives accurate results in less computational time compared to direct approach method.

Table 1. Comparison of Proposed and Direct approach [26] method of Load flow solution for 33 bus radial distribution system

Node no	Direct approach [26] Voltage (pu)	Direct approach [26] Angle (radian)	Proposed Voltage (pu)	Proposed Angle (radian)	Node no	Direct approach [26] Voltage (pu)	Direct approach [26] Angle (radian)	Proposed Voltage (pu)	Proposed Angle (radian)
1	1	0	1	0	**18**	**0.90378**	**-0.012089**	**0.90377**	**-0.012107**
2	0.99703	0.0002549	0.99703	0.0002377	19	0.9965	6.58E-05	0.9965	4.87E-05
3	0.98289	0.0016898	0.98289	0.0016728	20	0.99292	-0.0011032	0.99292	-0.0011204
4	0.97538	0.0028437	0.97538	0.0028268	21	0.99221	-0.0014411	0.99221	-0.0014582
5	0.96796	0.0040161	0.96796	0.0039992	22	0.99158	-0.0017962	0.99158	-0.0018134
6	0.94948	0.0023727	0.94948	0.0023557	23	0.97931	0.0011494	0.97931	0.0011323
7	0.94596	-0.0016709	0.94595	-0.0016881	24	0.97264	-0.0003994	0.97264	-0.0004165
8	0.9323	-0.0043498	0.9323	-0.0043672	25	0.96931	-0.0011622	0.96931	-0.0011793
9	0.92597	-0.0056502	0.92597	-0.0056677	26	0.94755	0.0030616	0.94755	0.0030447
10	0.9201	-0.0067632	0.92009	-0.0067807	27	0.94499	0.004042	0.94499	0.0040251
11	0.91923	-0.006634	0.91922	-0.0066515	28	0.93355	0.0054902	0.93354	0.0054734
12	0.91771	-0.0064293	0.91771	-0.0064468	29	0.92533	0.0068504	0.92532	0.0068337
13	0.91154	-0.0080551	0.91153	-0.0080727	30	0.92177	0.0086884	0.92177	0.0086718
14	0.90925	-0.0094564	0.90924	-0.0094741	31	0.91761	0.0072147	0.9176	0.0071979
15	0.90782	-0.010127	0.90782	-0.010145	32	0.91669	0.0068124	0.91669	0.0067956
16	0.90644	-0.010542	0.90643	-0.010559	33	0.91641	0.0066774	0.9164	0.0066606
17	0.90439	-0.011918	0.90439	-0.011936					
P_{loss}	210.98		211		Q_{loss}	143.02		143.13	
Time(s)	0.061		0.047						

4.1.2. 69-bus radial distribution System

The second case study is a 100 kVA, 12.66 kV, radial distribution system; it has 69 buses and 68 branches. The total load on 69-bus radial distribution system is 3.8013+j*2.6936 MVA [23]. The voltage profile, total active and reactive power losses obtained by Proposed Load flow method is given in Table.2 and also compared with existing direct approach method. Minimum voltage is 0.90919p.u occurred at bus 65 and total active and reactive power losses are 224.95 kW and 102.12 kVAR respectively. From results it can be observed that proposed load flow method gives accurate results in less computational time compared to direct approach method.

4.1.3. 33-bus mesh distribution System

Proposed load flow solution method is also easily adaptable for mesh distribution system, the third case study is a 100 kVA, 12.66 kV, mesh distribution system; it has 33 bus, 32 branches and 5 tie lines. The total load on 33-bus mesh distribution system is 3.715+j*2.3 MVA [22]. The voltage profile, total active and reactive power losses obtained by Proposed Load flow solution is given in Table 3 and also compared with existing direct approach method. Minimum voltage is 0.95322p.u occurred at bus 32 and total active and reactive power losses are 123.36kW and 88.44kVAR respectively. From results it can be observed that proposed load flow solution gives accurate results in less computational time compared to direct approach method.

Table 2. Comparison of Proposed Method and Direct approach [26] method of Load flow solution for 69 bus radial distribution system

Node no	Direct approach [26] Voltage (pu)	Direct approach [26] Angle (radian)	Proposed Voltage (pu)	Proposed Angle (radian)	Node no	Direct approach [26] Voltage (pu)	Direct approach [26] Angle (radian)	Proposed Voltage (pu)	Proposed Angle (radian)
1	1	0	1	0	36	0.99992	-5.18E-05	0.99992	-5.18E-05
2	0.99997	-2.14E-05	0.99997	-2.14E-05	37	0.99975	-0.0001637	0.99975	-0.0001637
3	0.99993	-4.28E-05	0.99993	-4.28E-05	38	0.99959	-0.0002059	0.99959	-0.0002059
4	0.99984	-0.0001027	0.99984	-0.0001027	39	0.99954	-0.0002181	0.99954	-0.0002181
5	0.99902	-0.000323	0.99902	-0.000323	40	0.99954	-0.0002187	0.99954	-0.0002187
6	0.99009	0.0008595	0.99009	0.0008595	41	0.99884	-0.0004105	0.99884	-0.0004105
7	0.9808	0.00211	0.9808	0.0021114	42	0.99855	-0.0004916	0.99855	-0.0004916
8	0.97859	0.00241	0.97858	0.0024114	43	0.99851	-0.0005022	0.99851	-0.0005022
9	0.97745	0.0025637	0.97745	0.0025651	44	0.9985	-0.0005049	0.9985	-0.0005049
10	0.97246	0.0040398	0.97246	0.0040413	45	0.99841	-0.0005365	0.99841	-0.0005365
11	0.97136	0.0043671	0.97136	0.0043686	46	0.9984	-0.0005366	0.9984	-0.0005353
12	0.9682	0.005286	0.9682	0.0052878	47	0.99979	-0.0001344	0.99979	-0.0001344
13	0.96528	0.0060922	0.96528	0.0060941	48	0.99854	-0.0009168	0.99854	-0.0009168
14	0.9624	0.0069087	0.96239	0.0068989	49	0.9947	-0.0033446	0.9947	-0.0033446
15	0.95954	0.0077123	0.95952	0.0077025	50	0.99415	-0.0036903	0.99415	-0.0036903
16	0.959	0.0078621	0.95899	0.0078523	51	0.97855	0.0024152	0.97855	0.0024165
17	0.95812	0.0081092	0.95811	0.0080995	52	0.97854	0.0024183	0.97854	0.0024198
18	0.95811	0.0081118	0.9581	0.008102	53	0.97467	0.0029463	0.97466	0.0029477
19	0.95765	0.0082608	0.95764	0.0082511	54	0.97142	0.0033934	0.97142	0.0033948
20	0.95735	0.0083575	0.95734	0.0083477	55	0.96695	0.0040144	0.96695	0.0040159
21	0.95687	0.0085126	0.95686	0.0085028	56	0.96258	0.0046245	0.96258	0.004626
22	0.95686	0.0085148	0.95685	0.0085051	57	0.94011	0.011545	0.9401	0.011547
23	0.95679	0.0085381	0.95678	0.0085284	58	0.92905	0.01508	0.92905	0.015083
24	0.95664	0.0085888	0.95662	0.0085791	59	0.92477	0.016493	0.92477	0.016496
25	0.95647	0.0086437	0.95646	0.008634	60	0.91975	0.018317	0.91974	0.01832
26	0.9564	0.0086663	0.95639	0.0086566	61	0.91235	0.019522	0.91235	0.019525
27	0.95638	0.0086727	0.95637	0.0086629	62	0.91206	0.01957	0.91206	0.019572
28	0.99993	-4.72E-05	0.99993	-4.72E-05	63	0.91168	0.019633	0.91167	0.019636
29	0.99985	-9.26E-05	0.99985	-9.24E-05	64	0.90978	0.019945	0.90977	0.019948
30	0.99973	-5.55E-05	0.99973	-5.41E-05	**65**	**0.9092**	**0.020039**	**0.90919**	**0.020041**
31	0.99971	-4.90E-05	0.99971	-4.73E-05	66	0.9713	0.0043872	0.9713	0.0043886
32	0.99961	-1.62E-05	0.9996	-1.34E-05	67	0.9713	0.0043874	0.9713	0.0043889
33	0.99935	6.10E-05	0.99935	6.64E-05	68	0.96787	0.0053917	0.96787	0.0053936
34	0.99901	0.0001632	0.99901	0.0001739	69	0.96787	0.0053921	0.96787	0.005394
35	0.99895	0.0001818	0.99894	0.0001925					
P_{loss}	224.87		224.95		Q_{loss}	102.10		102.121	
Time(s)	0.071		0.065						

Table 3. Comparison of Proposed and Direct approach [26] method of Load flow solution for 33 bus mesh distribution system

	Direct approach [26]		Proposed			Direct approach [26]		Proposed	
Node no	Voltage (pu)	Angle (radian)	Voltage (pu)	Angle (radian)	Node no	Voltage (pu)	Angle (radian)	Voltage (pu)	Angle (radian)
1	1	0	1	0	18	0.95382	-0.0033156	0.95382	-0.0033747
2	0.99709	0.000249	0.99708	0.0002323	19	0.9953	-3.23E-05	0.99529	-4.80E-05
3	0.98633	0.0009683	0.98632	0.0009489	20	0.98043	-0.0017253	0.98041	-0.0017317
4	0.98271	0.0010889	0.9827	0.0010691	21	0.97626	-0.0026953	0.97624	-0.0026989
5	0.97933	0.0011687	0.97932	0.0011485	22	0.97251	-0.0037935	0.97249	-0.0037876
6	0.97142	-0.0006183	0.97141	-0.0006398	23	0.98083	0.0008296	0.98082	0.0008082
7	0.9705	-0.0021054	0.97049	-0.0021262	24	0.97011	-0.0001586	0.9701	-0.0001842
8	0.96825	-0.0035914	0.96823	-0.0036069	25	0.96277	-0.0003405	0.96276	-0.0003704
9	0.96509	-0.0039853	0.96507	-0.0040029	26	0.9704	-0.0004422	0.97039	-0.0004646
10	0.96472	-0.0043448	0.96469	-0.0043303	27	0.96911	-0.0001845	0.9691	-0.000208
11	0.96473	-0.0043825	0.9647	-0.0043624	28	0.96384	-0.0003561	0.96383	-0.0003847
12	0.96489	-0.0044922	0.96485	-0.0044613	29	0.96026	-0.0002875	0.96025	-0.0003199
13	0.96152	-0.0044465	0.96146	-0.0043525	30	0.95702	0.000897	0.95701	0.0008602
14	0.96033	-0.0046872	0.96024	-0.0045674	31	0.9538	-0.0015297	0.9538	-0.0015766
15	0.95999	-0.0045773	0.96001	-0.0046645	**32**	**0.95322**	**-0.0022479**	**0.95322**	**-0.002298**
16	0.95825	-0.0041626	0.95827	-0.0042427	33	0.95341	-0.0027683	0.95341	-0.0028223
17	0.95485	-0.003944	0.95486	-0.0040102					
P_{loss}	123.357		123.36		Q_{loss}	88.33		88.44	
Time(s)	0.084		0.047						

4.2. Distribution systems with DG

In this paper work, two types of DG are considered. Although proposed method can handle all types of DG, but for comparison purpose the results of Type 1 and Type 3 are presented in this paper

- Type 1(operates at unity power factor): DG is capable of injecting real power only
- Type 3(operates at lagging power factor): DG is capable of injecting both real and reactive powers

The proposed method is compared with different methods, which are Exhaustive Load flow (ELF) [4], Improved Analytical (IA) [4], Mixed Integer Non-linear Programming (MINLP) [20], Particle Swarm Optimization (PSO) [11], Combined Power Loss Sensitivity (CPLS) [15], Voltage stability index (VSI) [21], Novel Method (NM) [15] and Modified Novel method (MNM) [15] for DG placement.

4.2.1. 33 Bus system with DG

From Fig. 5. it is observed that 6^{th} node is having high PLS factor, it means this node is most sensitive for real and reactive power loss for 33 bus system, DG placement on this node is more beneficial to the system.

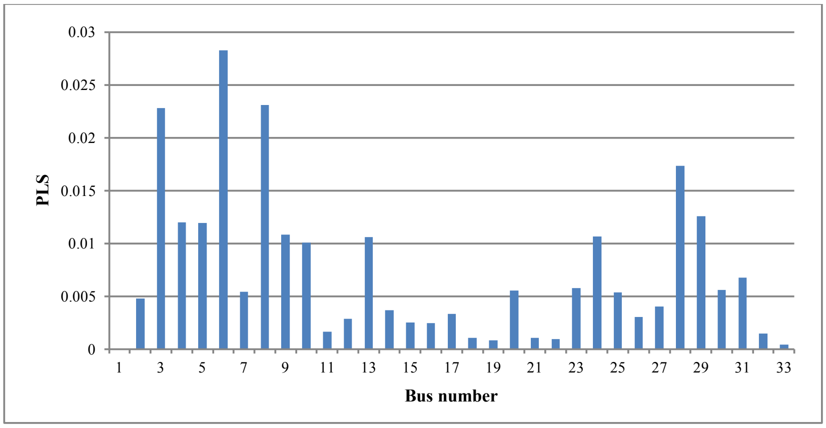

Fig. 5. PLS profile for 33-bus radial distribution system

a. *DG Type 1:*

Comparison of the proposed method and existing methods in Table 4. Expect CPLS method, optimal location of DG unit is same for all methods. Percentage loss reduction is same for all methods expect CPLS and NM. However computational time required by the proposed method is less.

Table 4. Comparison of existing methods and proposed method with DG Type 1 for 33-bus system

Method	Optimal Location	Optimal DG size (kW)	Losses(kW) Wodg*/Wdg*	Loss reduction(%)	Time (sec)
ELF[4]	6	2600	211.2/111.10	47.39	1.06
IA[4]	6	2600	211.2/111.10	47.39	0.16
MINLP[20]	6	2590	211/111.01	47.38	0.09
PSO[11]	6	2590	211.2/111.10	47.39	----
NM[15]	6	2494.8	210.98/111.14	47.32	----
CPLS[15]	8	1800	210.98/118.12	44.01	----
Proposed	**6**	**2565.563**	**211.00/111.00**	**47.39**	**0.047**

Wodg*-Without DG, Wdg*-With DG

Table 5. Comparison of existing methods and proposed method with DG Type 3 for 33-bus radial system

Method	Optimal location.	Optimal DG size		Total power (kVA)	Optimal Power factor	Losses(kW) Wodg/Wdg	Loss reduction(%)	Time (sec)
		kW	kVAR					
IA[4]	6	2547.74	1778.33	3107	0.82	211.2/67.90	67.85	----
MINLP[20]	6	2558	1761	3105	0.823	211/67.854	67.84	----
PSO[11]	6	2558.12	1745.68	3097	0.8259	211.2/67.90	67.85	----
MNM[15]	6	2710.17	1312.595	3011.3	0.9	210.98/70.9072	66.391	----
CPLS[15]	8	1890	915.368	2100	0.9	210.98/84.472	59.962	----
Proposed	**6**	**2533.266**	**1749.361**	**3078.588**	**0.823**	**211/67.8**	**67.86**	**0.047**

Wodg*-Without DG, Wdg*-With DG

b. *DG Type 3*:

Table 5, compares the existing methods and the propose method. Except in CPLS and MNM, optimal power factor of DG by all methods is almost same. Proposed method yields almost same percentage loss reduction, even though optimal DG size by proposed method is slightly less. It is observed that least percentage loss reduction in case of

CPLS method since optimal location and size with optimal power factor is not provided. Computational time required by proposed method is less. However, computational time of remaining method is not provided.

4.2.2. 69Bus system with DG

Similarly as in 33 bus system, from Fig. 6. it is observed that 61st bus is having high PLS factor, that means this node is most sensitive for real and reactive power loss, DG placement on this node is more beneficial to the system.

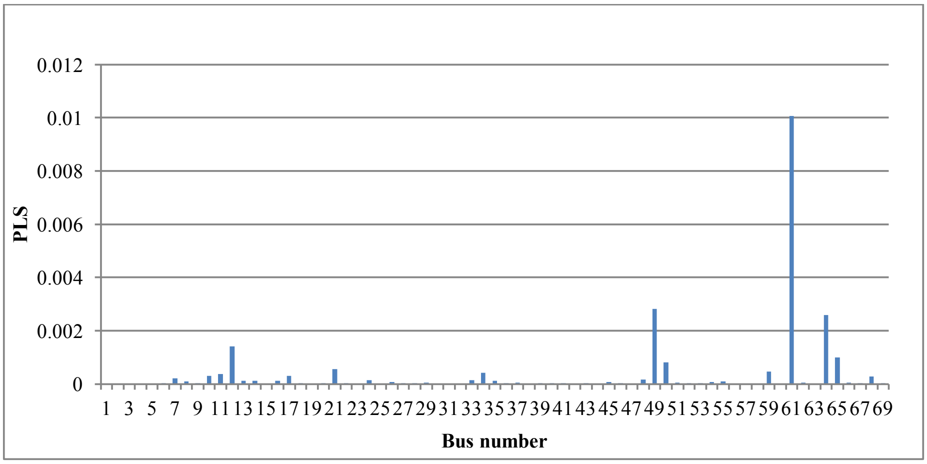

Fig. 6. PLS profile for 69-bus radial distribution system

Table 6. Comparison of existing methods and proposed method with DG Type 1 for 69-bus system

Method	Bus no.	DG power (kW)	Losses(kW) Wodg/Wdg	Loss reduction(%)	Time (sec)
ELF[4]	61	1900	219.28/81.33	62.91	7.75
IA[4]	61	1900	219.28/81.33	62.91	0.28
MINLP[20]	61	1870	225.27/83.48	62.94	----
PSO[11]	61	1806.2	219.28/78.74	64.09	----
NM[15]	61	1832.536	224.88/83.19	63.00	----
CPLS[15]	61	1850	224.88/83.15	63.02	----
VSI[21]	61	1870	224.86/83.14	63.02	
Proposed	**61**	**1887.767**	**224.95/83.15**	**63.03**	**0.078**

Wodg*-Without DG, Wdg*-With DG

a. *DG type 1:*

Comparison of the existing methods and the proposed method is given in Table 6. Optimal location of DG unit is same for all methods. Percentage loss reduction is slightly high by PSO method but in this method computational time consume for solution is not provided. CPLS and Proposed method yields same percentage loss reduction. However, CPLS consumes more computational time when compare to proposed method, since optimal DG size in CPLS method was determined by variation technique.

b. DG Type 3:

Comparison of the existing methods and the proposed method is given in Table 7. In CPLS and MNM, percentage loss reduction is almost same but less than other methods. Since, in these methods optimal power factor is not provided. PM method yields slightly high percentage loss reduction and also consumes less computational time.

Table 7. Comparison of existing methods and proposed method with DG Type 3 for 69-bus radial system

Method	Bus no.	DG power		Total power (kVA)	Optimal Power factor	Losses(kW) Wodg/Wdg	Loss reduction(%)	Time (sec)
		kW	kVAR					
IA[4]	61	1839	1284	2243	0.82	219.28/22.62	89.68	----
MINLP[20]	61	1828	1300	2244	0.815	225.27/23.31	89.65	----
PSO[11]	61	1818	1250	2207	0.824	219.28/22.62	89.68	----
MNM[15]	61	2013.0336	974.956	2236.704	0.9	224.88/27.38	87.82	----
CPLS[15]	61	1980	958.95	2200	0.9	224.88/27.91	87.59	----
VSI[21]	61	1814	1313.6	2240	0.81	224.86/23.12	89.71	----
Proposed	**61**	**1843.992**	**1311.221**	**2262.654**	**0.8149**	**224.95/23.12**	**89.72**	**0.078**

Wodg*-Without DG, Wdg*-With DG

4.3. Results of minimum and maximum voltages

The impact of DG Type 1 and DG Type 3 on the minimum and maximum voltages in both the 33-Bus and 69-Bus distribution networks are shown in Table 8. In all the methods after placement of DG, the total losses can reduce significantly while satisfying all the voltage and power constraints. However, percentage loss reduction and improvement in voltage profile by Type 3 is more compared to Type 1. Since, optimal deployment of both real & reactive powers from the DG operating at optimal power factor.

Table 8. Results of minimum and maximum voltages by different methods for 33-bus & 69-bus radial systems

Method	33 bus radial system				69 bus radial system			
	Minimum voltage (Bus no)		Maximum voltage (Bus no)		Minimum voltage (Bus no)		Maximum voltage (Bus no)	
	Type 1	Type 3	Type 1	Type 3	Type 1	Type 3	Type 1	Type 3
IA[4]	0.9425(18)	0.9575(18)	1.0000(1)	1.0007(1)	0.9692(27)	0.9732(27)	1.0000(1)	1.0000(1)
MINLP[20]	0.9424(18)	0.9584(18)	1.0000(1)	1.0010(1)	0.9682(27)	0.9724(27)	1.0000(1)	1.0000(1)
PSO[11]	0.9424(18)	0.9598(18)	1.0000(1)	1.0029(1)	0.9681(27)	0.9724(27)	1.0000(1)	1.0000(1)
NM & MNM[15]	0.9412(18)	0.9566(18)	1.0000(1)	1.0000(1)	0.9685(27)	0.9728(27)	1.0000(1)	1.0000(1)
CPLS[15]	0.9433(18)	0.9534(18)	1.0000(1)	1.0000(1)	0.9685(27)	0.9726(27)	1.0000(1)	1.0000(1)
VSI[21]	-----	------	------	-----	0.9686(26)	0.9727(26)	1.0000(1)	1.0000(1)
Proposed	**0.9420(18)**	**0.95788(18)**	**1.0000(1)**	**1.0000(1)**	**0.9684(27)**	**0.9726(27)**	**1.0000(1)**	**1.0000(1)**

5. Conclusion

This paper has presented a novel application of GAMS software to perform load flow solution for both radial/mesh distribution systems. Besides, two-phase scheme has been proposed for DG allocation in distribution system. In first phase, sensitive candidate nodes are selected as optimal DG location based on Power Loss Sensitivity (PLS) and second phase, optimal DG size are computed by using CONOPT solver of GAMS. The proposed method is tested on IEEE 33-bus and IEEE 69-bus test systems. From comparative analysis, it can be observed that the proposed method produced superior results than existing methods in respect of loss reduction, improvement in voltage profile and computational time.

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