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A Multiobjective Approach for Optimal Distributed Generators Planning in Distribution System using Backtracking Search considering Load Models

[1]Vivek Gupta, [2]Sumit Khare, [3]Rohit Kumar Sinha
Department of Electrical Engineering,
National Institute of Technology, Warangal

***Abstract*-** **The continuous rise in power demand and limited resources has attracted the concern for Distributed Generators, DGs. DGs not only reduce system losses, improve voltage profile but also improve the system reliability. With the advancement of renewable technologies like wind energy, solar energy, etc., the optimal DG planning becomes important. In this paper a multi-objective weighted method considering active power loss, reactive power loss and voltage deviation had been used to find the best location and size of DGs. The proposed method has been tested on IEEE 33 bus and 69 bus systems, considering various load models and DG operating power factors of 0.85, 0.9 and unity.**

Index Terms- DG, BSA, multiobjective, ploss, qloss, voltage deviation.

I. INTRODUCTION

DEREGULATION in power system has increased the interest of power system planners towards Distributed Generators (DGs). DGs may play a pivotal role in distribution system in the near future due to their added advantages like improving losses, increasing reliability, environment friendly, etc. The DGs can work both in grid connected and standalone mode which make them feed local loads even during grid failure. The two blackouts in northern and eastern grids in India in 2012 also shows the need of DGs in present day scenario.

DG planning had always been a key area of interest of many researchers and lot of work had been done in this context considering different objectives. Optimal DG placement considering voltage stability margin had been studied by Abri *et al* [1]. The authors of [2] had used ABC optimization technique to find optimal DG size, power factor and location considering active power loss as the network constraint. Reliability improvement of the distribution system in presence of DGs had been dealt in [3] with an objective to minimize SAIDI, CAIDI and ENS indices for time varying loads.

Rajesh *et al* [4] had tried to enhance the distribution reliability using distributed generators operating in standalone mode. Analytical approach for DG placement had been discussed in [5]. Optimal DG placement considering various load models had been considered by Zonkoly [6] using PSO technique. The authors of [7] had used a multi-objective approach for DG placement and sizing using PSO. The DG optimization based on loss reduction and improving voltage stability had been dealt in [8]. Genetic Algorithm had been found useful in dealing with DG placement and sizing [9].

The paper by Pavlos *et al* [10] had compiled various methods, optimization techniques, constraints, etc. which had already being used for DG placement as well as the future research which can be done in this area.

This paper deals with a multiobjective approach for DG placement in distribution system considering load models using a new evolutionary algorithm [11], Backtracking Search Optimization Algorithm (BSA). Here, weighted search method is used considering active power loss, reactive power loss and voltage deviation as the constraints.

II. PROBLEM FORMULATION

The problem statement here is to reduce active power loss, reactive power loss as well as voltage deviation in distribution system.

(A). Objective Function:

$$\text{Min.: } Fn() = Wp * IP_L + Wq * IQ_L + Wv * IV_{dev.}, \quad (1)$$

$$Wp + Wq + Wv = 1 \quad (2)$$

Where, IP_L, IQ_L, and IV_{dev} are the indices for active power loss, reactive power loss and voltage deviation respectively. Wp, Wq and Wv are the weight factors assigned to them by the system planners based on the importance of various objectives. Here Wp=40%, Wq=30% and Wv=30% had been considered.

IP_L, IQ_L, and IV_{dev} are the indices used to inspect the DG location and sizing in comparison to the original system considered. The load flow results of the original network acts as base case values for the indices computation.

$$IP_L = P_{Lnth} / P_{Lo} \quad (3)$$

$$IQ_L = Q_{Lnth} / Q_{Lo} \quad (4)$$

$$IV_{dev} = V_{devnth} / V_{devo} \quad (5)$$

Where, P_{Lnth} , Q_{Lnth} , and V_{devnth} are the power losses and voltage deviation for the *n*th installation combination; P_{L0} , Q_{L0} , and V_{dev0} are the adopted original network power losses and voltage deviation when no DG was installed.

The studies had been done by evaluation the objective function values against the given indices, the best result is chosen to be the one which minimizes all the indices based on their corresponding weights.

(B). Constraints:

Line power transfer limits and voltage limits are enforced.

$$|Pline_{ij}| \le |P\max_{ij}| \quad (6)$$

$$V_{\min} \le V \le V_{\max} \quad (7)$$

In eq. (6) $|Pline_{ij}|$ is the total power flow through the line ij and $|P\max_{ij}|$ is the maximum allowable power flow through the line. In eq. (7) V_{min} and V_{max} are minimum and maximum allowable voltages for a given bus.

(C).Forward Backward Sweep Load Flow:

The distribution system is very much different from the transmission system as it is more of radial system with low X/R ratio. Thus the conventional load flows like N.R, Gauss Siedel etc. fails to converge [8] or are not reliable. Hence in this paper forward backward (fb) sweep load flow [10] is used to compute load flow.

$$V_{a''} = V_a - Z_{aa'} * I_a \quad (8)$$

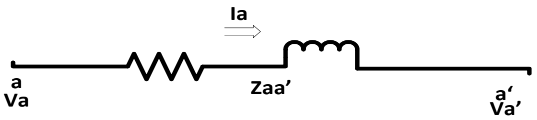

Fig.1. Typical Single Phase Feeder

$$Il_i = (P_i - jQ_i)/V_i^* \qquad i=1..............nb \quad (9)$$

Figure 1 shows the typical section of a single phase feeder. The fb sweep considers the complex load at each bus to be constant. The load is then converted into equivalent current injection at each bus using equation 9. The fb sweep method takes two steps in each iteration. The first step is called backward sweep wherein starting from the last bus we calculate the branch current till the first bus, given by (10). Now the second step is called forward sweep wherein starting from the first bus, voltage is calculated for all the buses using equation (8).

$$I_j = \text{Current of' j'th branch} = \sum Il_i \, , \quad (10)$$

where, i=all subsequent buses to 'j'

III. VOLTAGE DEPENDENT LOAD MODEL

While studying distribution loads, most of the times loads are assumed as constant. However, it is not the case always, as quoted in [12], [13] in more practical scenario the loads are considered to be voltage dependent and based on their relationship they are classified as commercial, residential and industrial loads. In this voltage dependent load model the relation between voltage and load is expressed as:

$$P_l = P_{lo} * V^{\alpha} \quad (11)$$

$$Q_l = Q_{lo} * V^{\beta} \quad (12)$$

Where α and β are the active and reactive power exponents as given in table I, P_{lo} and Q_{lo} are the active and the reactive powers at nominal voltages respectively while P_l and Q_l are the powers at given voltage levels. For mixed type [13] different buses are loaded with different load types i.e. mixed load model contains a mix of all the types of loads placed at different buses of the system.

TABLE I
LOAD TYPES AND EXPONENT VALUES

Load Type	α	β
Constant	0	0
Industrial	0.18	6
Residential	0.92	4.04
Commercial	1.51	3.04
Mixed	-	-

IV. BACKTRACKING SEARCH OPTIMIZATION

BSA is a new evolutionary optimization algorithm similar to PSO and GA. Optimization algorithms are mainly used to get the most reliable results of the various results available in the search space. A good optimization algorithm is one which does not get struck in the local minima and get the most optimized values. It has simple structure which is easy to implement and does not depend much on the initial values of the parameters. BSA is a dual-population algorithm that uses both the current and historical populations. Unlike most other optimizations which maximize the objective function, it minimizes the objective function.

BSA can be explained in five steps[11], initialization, selection-I, mutation, crossover and selection-II. The flowchart for the method is given in Fig.2.

(1). *Initialization:*

This step involves generation of initial population based on size and problem dimension.

$$P_{ij} \sim U(low_i \, , \, up_i)$$

(2). *Selection-I:*

It uses historical population oldP to find the search direction.

$$\text{old } P_{ij} \sim U(low_i, up_i)$$

Then the old population is randomly shuffled:

oldP:=permuting(oldP)

(3). *Mutation:*

This process generates the trial population i.e *mutant.*

$$Mutant = P + F.(oldP - P)$$

Here, F controls the amplitude of the search-direction matrix.

(4). *Crossover:*

It generates the final population to be used, here population with better fitness are used to generate the target population.

(5). *Selection-II:*

In this process the individuals with better fitness are chosen to update the population and global minimizer is set to P_{best} and its fitness is updated as global minimum.

V. METHODOLOGY

a). Optimal Placement of DG

Optimal DG placement basically involves fulfillment of one or more objectives without compromising on bus voltages, line loadings and the system reliability. Here the system active and reactive losses are minimized along with minimizing the voltage deviation of the system. This is achieved by searching the potentially best position and size of DGs and enforcing the bus voltages to lie within 5% of the base voltage.

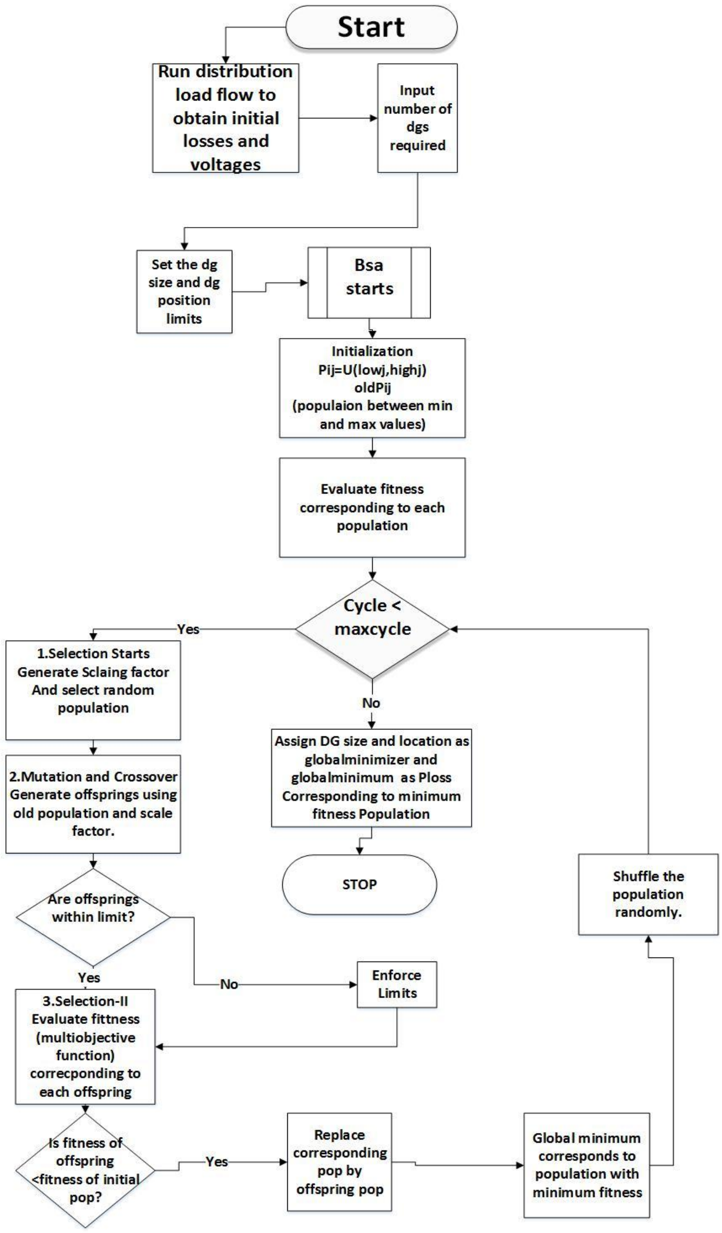

Fig. 2. Flowchart of BSA for optimal DG placement.

b). BSA for Optimal Placement

BSA is a new optimization algorithm which unlike many other algorithms aims at minimizing the objective function. It uses two sets of populations, one trial population and other as historical population which acts as swarm memory. Thus the offsprings contains the characteristics of both present and historical population which is helpful in obtaining quick and reliable results. The probable locations for the DG can be anywhere between first bus to the total number of buses while the DG size is considered to lie between 0 MW to 1.2 MW for a 33 bus system and 0 MW to 2 MW for a 69 bus system.

TABLE II:
OPTIMIZATION RESULTS FOR VARIOUS LOAD MODELS ON 69 BUS SYSTEM WITH DGs OPERATING AT p.f. of 0.85

No. of DGs	Size/Position (MW)	Ploss (kW)	Qloss (kVars)	Min.V (p.u)
	Constant Load			
1	1.923 (61)	23.862	14.637	0.9727 (27)
2	1.818 (61) 0.556 (17)	7.957	8.327	0.9942 (50)
3	1.848 (61) 0.775 (50) 0.615(16)	6.100	2.824	0.9964 (69)
	Industrial Load			
1	1.858 (61)	21.850	13.507	0.9731 (27)
2	1.800 (61) 0.534 (17)	7.453	8.019	0.9944 (50)
3	1.804 (61) 0.746 (49) 0.479(23)	5.999	2.945	0.9936 (69)
	Residential Load			
1	1.858 (61)	22.080	13.625	0.9733 (27)
2	1.804 (61) 0.536(17)	7.604	8.087	0.9943 (50)
3	1.907 (61) 0.684 (50) 0.584 (15)	6.419	2.937	0.9963 (69)
	Commercial Load			
1	1.851 (61)	22.068	13.598	0.9734 (27)
2	1.802 (61) 0.536 (17)	7.654	8.097	0.9943 (50)
3	1.697 (61) 0.673 (49) 0.504 (19)	6.039	3.192	0.9934 (69)
	Mixed Load			
1	1.858 (61)	21.850	13.507	0.9733 (27)
2	1.785 (61) 0.530 (18)	7.431	1.785	0.9944 (50)
3	1.802 (61) 0.831 (49) 0.541 (18)	5.260	2.602	0.9948 (69)

The objective function is evaluated for trial population using the weighted method considering IP_L, IQ_L, and IV_{dev} indices. Then using mutation, crossover and selection processes new population (offsprings) are generated. The objective function is calculated for the offsprings, the offsprings with lower fitness value replace the members from initial population thus creating a new set of population with lower fitness. The difference between the fitness of trial and historical population decide the direction operation of the optimization. The BSA steps are repeated until maximum cycles are met where the global minimizer contains the best DG location and sizes.

TABLE III:
OPTIMIZATION RESULTS FOR VARIOUS DG OPERATING POWER FACTORS ON 33 BUS SYSTEM

Operating Power Factor	Number of DGs Placed	DG Size (MW)/ Location	Ploss (KW)	Qloss (KVars)	Minimum Voltage /Bus Number
Unity	1	1.2 (30)	121.35	83.31	0.9314 (18)
	2	1.16 (30) 0.84 (13)	85.91	58.60	0.9685 (33)
	3	1.07 (30) 1.17 (24) 0.81 (13)	71.52	49.52	0.9697 (33)
0.9	1	1.2 (30)	82.58	57.28	0.9373 (18)
	2	1.2 (30) 0.99 (12)	35.58	25.03	0.9803 (25)
	3	1.2 (30) 1.04 (24) 0.91 (12)	19.08	14.74	0.9879 (18)
0.85	1	1.2 (30)	76.14	53.09	0.9389 (18)
	2	1.2 (30) 0.92 (12)	31.26	22.24	0.9805 (25)
	3	1.2 (30) 1.0 (24) 0.78 (13)	14.62	11.86	0.9940 (22)

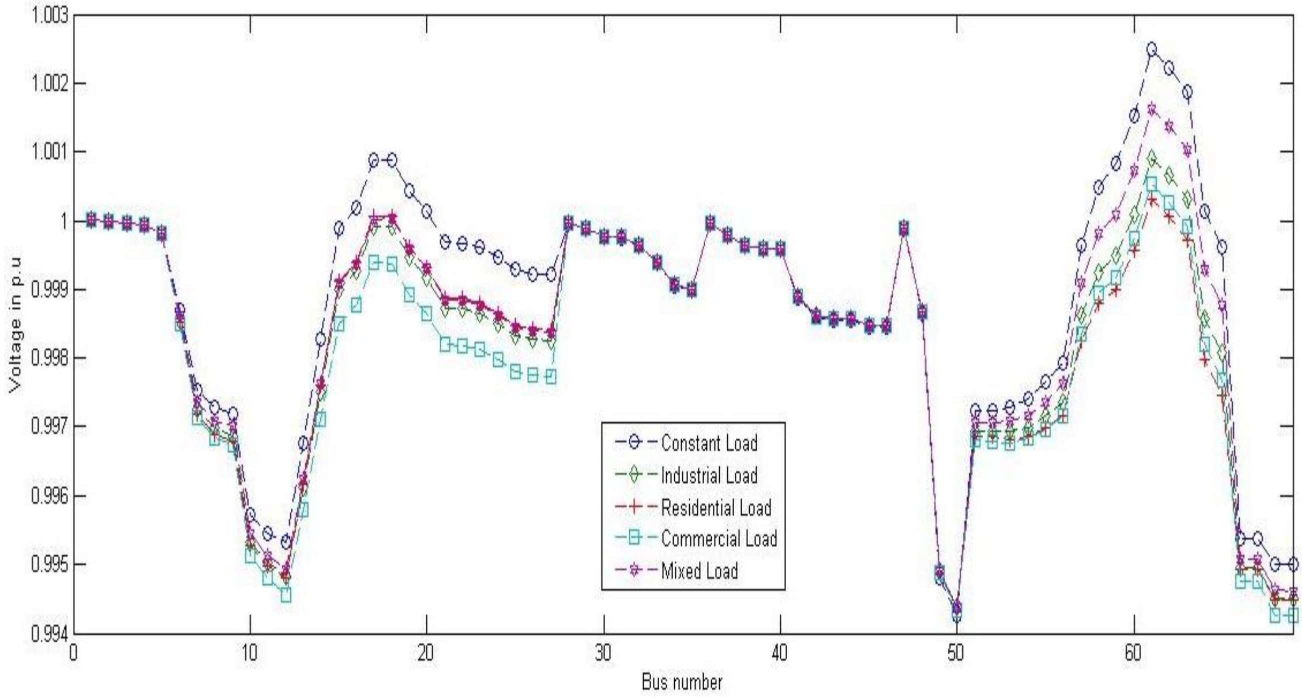

Fig. 3: Voltage profile for multi-objective DG placement on 69 bus system considering various load model with 2 DGs placed operating at 0.85 pf.

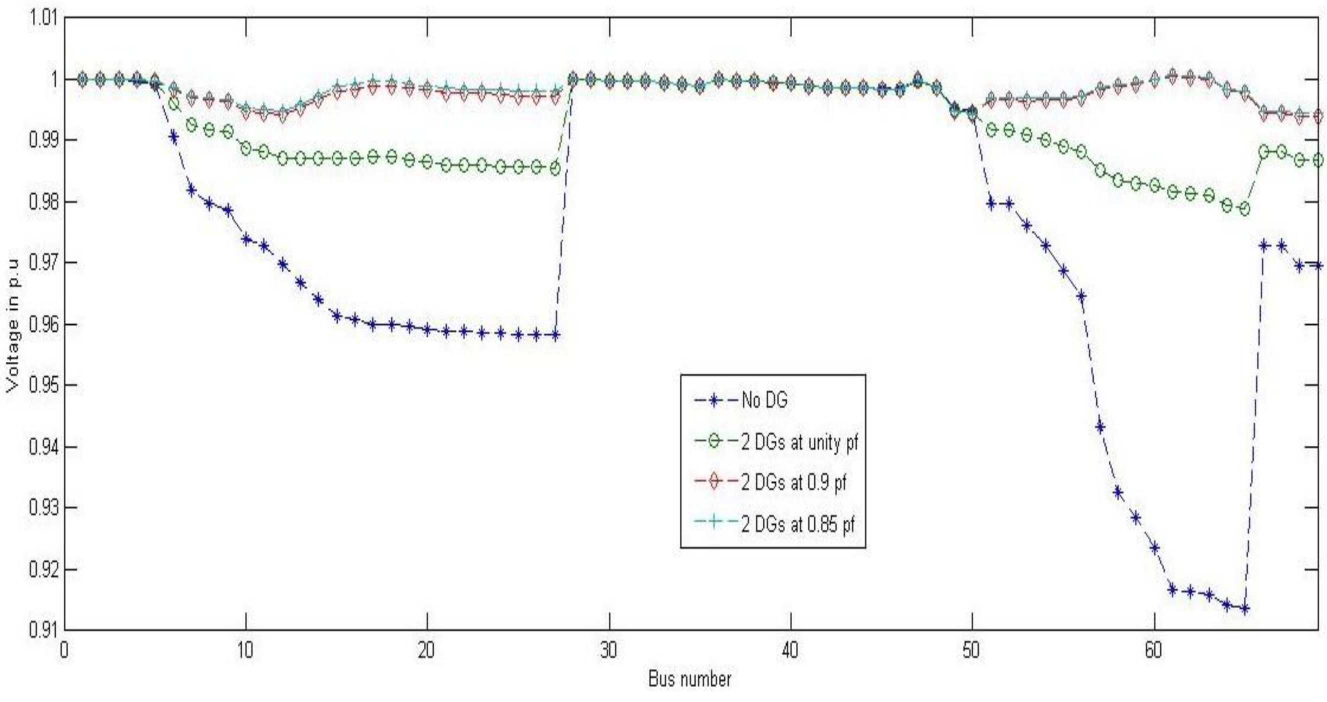

Fig. 4: Voltage profile for multi-objective DG placement on 69 bus system with 2 DGs placed operating at varying power factors on mixed load model.

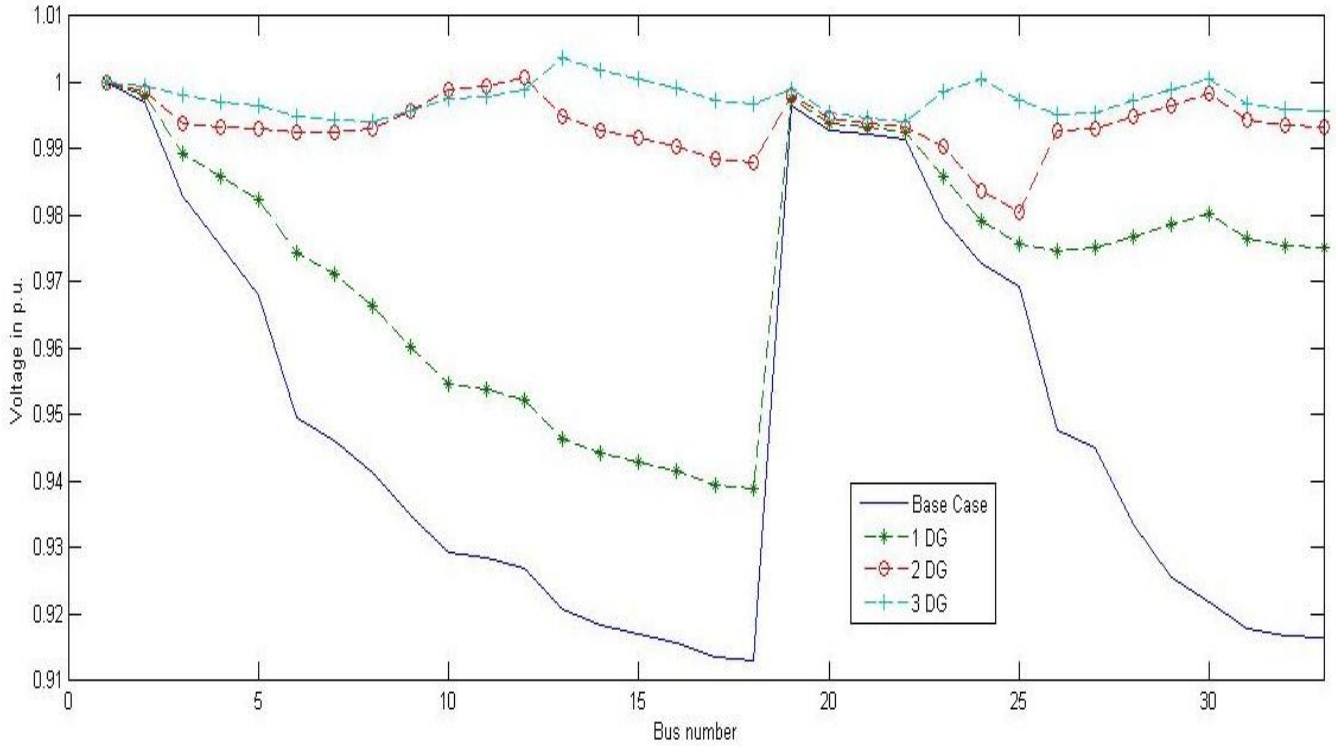

Figure 5: Voltage profile before and after placing DGs operating on power factor 0.85 on IEEE 33-bus system.

TABLE III:
OPTIMIZATION RESULTS FOR COMMERCIAL AND MIXED LOAD MODELS ON 69 BUS SYSTEM WITH VARIOUS NUMBER OF DGs AND OPERATING POWER FACTORS

No. of DGs	Power factor	Position	Size (MW)	Ploss (kW)	Qloss (kW)	Min V (p.u)	Position	Size (MW)	Ploss (kW)	Qloss (kW)	Min V (p.u)
		Commercial load					Mixed load				
1	Unity	61	1.791	72.51	35.61	0.9693 (27)	61	1.802	68.67	33.94	0.9692 (27)
	0.9	61	1.926	25.13	14.99	0.9730 (27)	61	1.924	24.23	14.59	0.9729 (27)
	0.85	61	1.851	22.068	13.598	0.9734 (27)	61	1.858	21.850	13.507	0.9733 (27)
2	Unity	61 18	1.731 0.426	65.09	32.94	0.9785 (65)	61 18	1.737 0.395	62.13	31.66	0.9785 (65)
	0.9	61 17	1.867 0.531	11.49	9.82	0.9938 (69)	61 17	1.864 0.519	11.02	9.62	0.9936 (69)
	0.85	61 17	1.802 0.536	7.654	8.097	0.9943 (69)	61 18	1.785 0.530	7.431	1.785	0.9944 (50)
3	Unity	61 49 18	1.728 0.765 0.417	63.63	29.34	0.9783 (65)	61 49 18	1.726 0.837 0.383	60.65	28.01	0.9781 (65)
	0.9	61 19 11	1.836 0.363 0.523	9.21	8.87	0.9943 (50)	61 50 17	1.828 0.773 0.486	9.00	4.43	0.9927 (69)
	0.85	61 49 19	1.697 0.673 0.504	6.039	3.192	0.9934 (69)	61 49 18	1.802 0.831 0.541	5.260	2.602	0.9948 (50)

VI. RESULTS and DISCUSSION

The optimization had been applied to IEEE-33 bus and IEEE-69 bus radial distribution system. Under base case condition for 33 bus system the total real power loss of the system is 202.5088 KW and the reactive power loss is 135.1286 KVARS. The minimum voltage is 0.9131 p.u which occurs at bus number 18. However, even with a single DG operating at unity power factor the real power loss is reduced to 121.35 KW and reactive power loss reduced to 83.31 KVars and the minimum system voltage shoots up to 0.9314 p.u. For 69 bus system the real power loss without DG is 224.8687 KW, reactive power loss is 102.0455 KVars and minimum bus voltage is 0.9092 which occurs at bus number 65. However with a single DG operating at power factor of 0.85 for constant load model the active power loss is reduced to 23.862 KW, reactive power loss is reduced to 14.637 KVars and the minimum bus voltage shoots up to 0.9727 p.u. There is significant improvement in the voltage profile of both the bus systems as well as the losses have significantly reduced as can be seen from the tables and the figures attached to support the claim.

The studies had been done on various load models which further shows that the method is significantly good in voltage dependent or varying loads which further makes it useful in more practical scenario. The improvement in results also shows how DGs can be significant in better operation of our distribution system.

VII.CONCLUSION

In this paper a new evolutionary algorithm, BSA, has been used. The results show that the method is better than most of the other algorithms present in literature. Multi-objective optimization is used which makes better siting and sizing based on the level of importance of each objective. The load flow used is applicable for low X/R ratio where most of the traditional load flows fail to converge. Hence the method is applicable for ill conditioned systems also.

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