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MULTI-DG PLACEMENT IN PRACTICAL DISTRIBUTION SYSTEM FOR MAXIMUM COST SAVING WITH INCREASING LOAD SCENARIO

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ABSTRACT

The primary objective of this paper is to maximise the cost saving of the distribution system when Distributed Generation (DG) is integrated. For which an objective function is developed to represents the savings of the system. But the maximization of the function mainly relies on the locations and sizes of the DG. Fuzzy logic approach is implemented for generating the optimal DG location indices based on the rule base framed and with effective inputs: real power loss index and voltage index. Gravitational Search Algorithm (GSA) is computed to find the appropriate capacity of DG in the locations preferred, so as to maximise the desired objective function. In this paper, a planning period of 10 years is considered for finding the maximum cost savings. Inflation rate and interest rate were considered to estimate the present cost value of the system and every year 2% of load is assumed to increase w.r.t. the base load. The results have been compared for the single and multi DG placement. The proposed algorithm is coded in MATLAB environment and is tested on an Indian 43-bus practical distribution system. The results obtained are discussed and presented.

Keywords: distributed generation, cost analysis of DG, fuzzy logic approach, practical distribution systems, gravitational search algorithm, increasing load scenario, inflation rate, interest rate.

1. INTRODUCTION

Distributed Generation (DG) is a small scale of renewable and conventional power source, like solar, wind, small hydro etc... It is connected at distribution voltage level near customer end. The DG is well recognised as environmental friendly which can improve the voltage profile, reduce losses and congestion of the system, provided a proper location and size of the same is concerned [1]. There are plenty of research papers available which deals with placement, sizing and cost analysis of DG into the distribution systems. In [2] *Naresh et al* examined that the incorrect placement and sizing of DG leads to the increase of losses in the system, which explains the importance of DG location and its size. In [3] *Wang* el al proposed an analytical method for placing DG with power factor control to reduce the losses. *Vijaykumar et al* [4] proposed a method for maximization of saving and reducing the losses by optimally placing and sizing DG. *Satish et al* [5] proposed a simple method based on maximum benefit for choosing the location and site for optimal capacitor and DG. In [6] *shukla et al* has proposed a method for estimating the economic saving of the system, which has translated from the performance improvement resulted post DG placement.

This paper is organized as follows section-2 presents the problem formulation where the objective function is framed for maximum saving of the system is given. In section-3 Fuzzy approach is implemented for generating the optimal DG locations. Section-4 presents the Gravitational Search Algorithm for sizing DG the capacities. The last section discusses the results and their implications and finally followed by conclusion and references.

2. PROBLEM FORMULATION

The prime objective of this study is to increase the cost saving of the system by optimally placing the DG. The mathematical model of the objective function representing saving for the system is given through equation (1). The maximization of the objective function mainly depends on the DG location and size.

$$\max(F) = C_{MS} \tag{1}$$

Where, *'F'* is the objective function of the system, and C_{MS} is the cost of maximum saving.

2.1 Cost of maximum saving

The cost of maximum saving is calculated as the cumulative difference between the benefits obtained and the expenses incurred for DG placement over a planning period of 10 years, as given in equation (2).

$$C_{MS} = \sum Benefit - \sum Expenses \tag{2}$$

The benefit of the system is the combination of cost of energy loss and cost of DG generated power which is given in equation (3)

$$\sum Benefits = \left\{ \underbrace{\sum \left(NLR \cdot K_{ES} \right)}_{C_{NLR}} + \underbrace{\sum \left(X_{DG} \cdot K_{DG,gen} \right)}_{C_{DG,gen}} \right\} \tag{3}$$

Where,

NLR = Net loss reduction which is the difference of the system loss without and with DG placement, kW.
K_{ES} = Cost of energy saving, \$/kW-yr,
$K_{DG, Gen}$ = Cost of DG power generated, \$/kW-yr,
X_{DG} = Capacity of DG, kW
C_{NLR} = Cumulative cost of Net loss reduction, \$
$C_{DG, Gen}$ = Cumulative cost of DG generated power, \$

The expenses of the system is the summation of DG investment cost and the cumulative sum of DG operation and maintenance cost

$$\sum Expenses = \left\{ \underbrace{\sum\left(X_{DG} \cdot K_{DG,O\&M}\right)}_{C_{DG,O\&M}} + \underbrace{\left(X_{DG} \cdot K_{DG,Inv}\right)}_{C_{DG,Inv}} \right\} \quad (4)$$

Where,

$K_{DG, O\&M}$ = Cost of DG Operation and Maintenance, \$/kW-yr,
$K_{DG, Inv}$ = Cost of DG investment, \$/kW
$C_{DG, O\&M}$ = Cumulative cost of DG O&M, \$
$C_{DG, Inv}$ = Total Cost of DG investment, \$

2.2 Net present value [5]

The present value of various cost discussed above are calculated using the equation (5) shown below. The net present value factor (γ) which includes inflation rate (*IF*) and interest rate (IR) [5], is multiplied with the varying costs for estimating the present value. The cost analysis is been carried over a planning period (*Np*) of 10 years.

$$\gamma^t = \sum_{t=1}^{N_p}\left(\frac{1+IF}{1+IR}\right)^t, \text{ Where t = 1,2,3,…,} N_p \quad (5)$$

3. FUZZY APPROACH FOR FINDING OPTIMAL DG PLACES

In this section Fuzzy logic approach is described which generates the optimal DG location by approximating over the inputs using the rule base (given in Table-1 [7-8]. Real loss index (RLI) and voltage index (VI) were calculated and given as input to the fuzzy inference engine as shown in Figure-1.

The real loss indices are the normalised values of observed real power loss reduction, when the load at i^{th}bus is removed. The buses having high values of this index are selected for consideration for placing DG. It is given through equation (6). The voltage index is calculated by the normalizing the voltage values between 0 and 1. The buses having low value of this index are given priority for selection. The output of the inference system is the DG location index (DGLI) and the buses having the high value are chosen as optimal choice for placing DG. Figures (2-4) shows the membership function of *RLI, VI* and *DGLI* used in the process. Table-2 shows the location index values of the 43 bus practical system. It can be observed that bus 22 has highest index value followed by bus 35 and so on.

$$RLI = P_{loss} - P_{loss,0}(i) \quad (6)$$

Where,
i = $1, 2\ldots N_b$ buses
P_{loss} = Power loss for normal load,
$P_{loss,0}(i)$ = Power loss for zero load at ith bus.

Table-1. Decision matrix for optimal DG location [8].

AND		VI				
		L	LN	N	HN	H
RLI	L	LM	LM	L	L	L
	LM	M	LM	LM	L	L
	M	HM	M	LM	L	L
	HM	HM	HM	M	LM	L
	H	H	HM	M	LM	LM

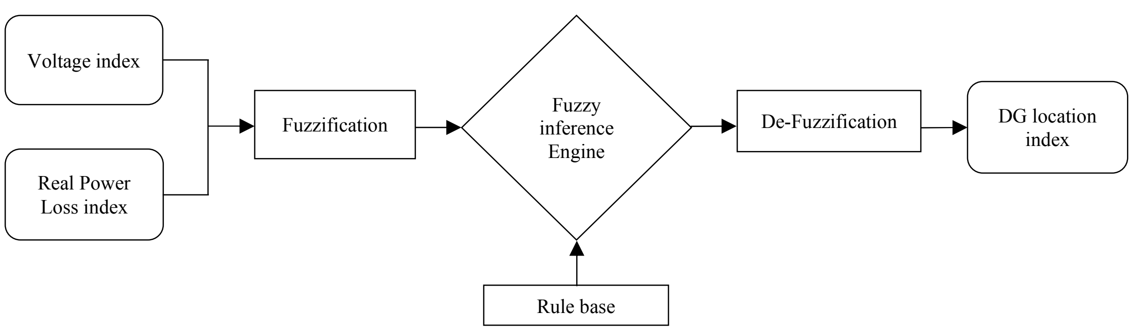

Figure-1. Flow chart for finding optimal DG locations.

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Table-2. DG location index for 43-bus practical system.

Bus no.	RLI index	Voltage index	DG location index
22	1.000	0.183	0.760
35	0.779	0.000	0.752
34	0.778	0.003	0.752
33	0.772	0.011	0.751
32	0.763	0.023	0.751

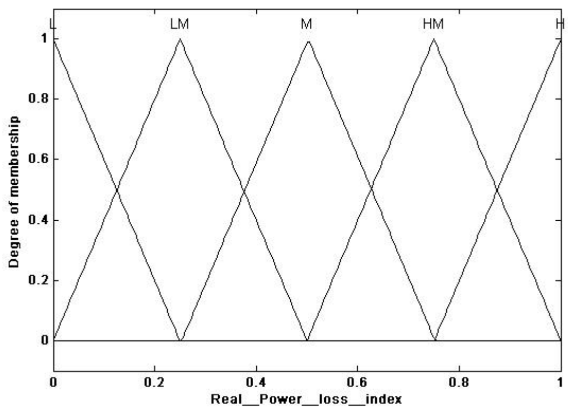

Figure-2. Membership functions for RPL index.

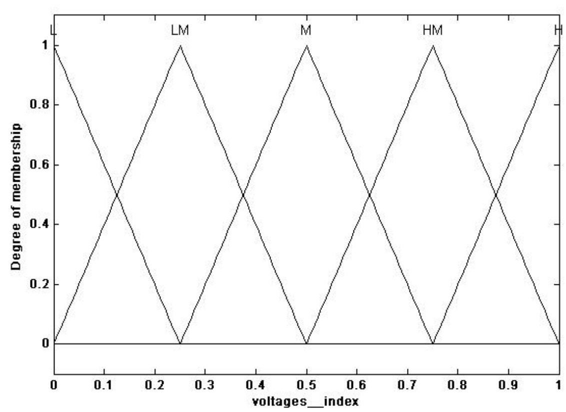

Figure-3. Membership function for VI index.

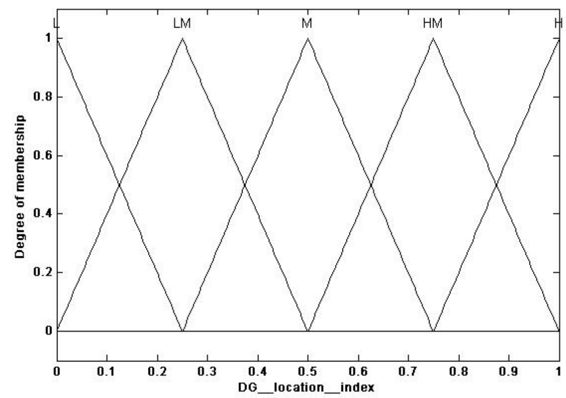

Figure-4. Membership function for DGLI index.

4. OVERVIEW OF GRAVITATIONAL SEARCH ALGORITHM

In 2009 Rashedi *et al* [9, 10] proposed the GSA algorithm which mainly developed based on the law of gravity and interaction of masses. In this algorithm, based on Newton law of gravity and law of motion, the group of masses which regarded as solution agents interacts with each other. The position of each mass has a solution. The position of heaviest mass has the best solution and it attracts the surrounding masses which are accelerated by their gravitational and inertial masses. In this study GSA is computed to optimize the size of DG.

4.1. Algorithm for DG sizing using GSA [10]

Step 1: Generate "*N*" number of masses $\left(X_1, X_2, X_3, \ldots, X_i, \ldots, X_N\right)$ and their velocity within the limits. Initialize the generation limit T = 100 and set current iteration count (t) to one.

The position of the i^{th} mass is given by, $X_i = \left(X_i^1, X_i^2, X_i^3, \ldots, X_i^d, \ldots, X_i^n\right)$, where X_i^d represents the position of the i^{th} agent in the d^{th} dimension.

Step 2: Using equation (7), calculate the force on the i^{th} mass by the j^{th} mass in the d^{th} dimension.

$$F_{ij}(t) = G \times \frac{M_{pi}(t) \times M_{ai}(t)}{R_{ij}(t) + \varepsilon} \times \left(X_j^d(t) - X_i^d(t)\right) \quad (7)$$

Where,

$M_{pi}(t)$ = Active gravitational mass related to agent j,

$M_{ai}(t)$ = Passive gravitational mass related to agent i,

G = Gravitational constant,

ε = Small constant, and

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$R_{ij}(t)$ = Euclidian distance between two agents i and j, which is given in equation (8)

$$R_{ij}(t)=\left\|X_i(t)-X_j(t)\right\|_2 \tag{8}$$

The total force that acts on i^{th} mass, in a dimension d be a randomly weighted sum of d^{th} components of the forces exerted from other agents.

$$F_i^d(t)=\sum_{i=1,\, j\neq i}^{N} rand_i \cdot F_{ij}^d(t) \tag{9}$$

Where, *rand* = random number generated between 0 and 1.

Step 3: Calculate the acceleration of i^{th} mass using equation (10)

$$a_i^d(t)=\frac{F_i^d(t)}{M_{ii}(t)} \tag{10}$$

Where $M_{ii}(t)$ is the inertial mass of the i^{th} agent.

Step 4: Update the velocity and position of all the masses using equations (11-12)

$$V_i^d(t+1)=rand_i \times V_i^d(t)+a_i^d(t) \tag{11}$$

$$X_i^d(t+1)=X_i^d(t)+V_i^d(t) \tag{12}$$

Step 5: Calculate the objective value of each mass using equation (1)

Step 6: Check for the tolerance or generation limit reached. If yes go to step 8, else go to step 7

Step 7: Increase the iteration count and go to step 3

Step 8: The heaviest mass in the population gives the best fitness value i.e. maximum loss reduction and position of that mass gives the optimal DG sizes.

Table-3. System parameters of 43-bus system for the first year in planning period.

Description	Without DG	Single DG	Multi DG
P_{loss},kW	165.9362	128.6523	113.6443
Q_{loss}, kVAR	105.8952	82.1027	72.5243
Total loss reduction with DG, kW	N/A	37.2839	52.2921
DG Location	N/A	Bus 22	Bus 22, Bus 35
DG Capacity, kW	N/A	706.3952	250.3407, 705.2986

Table-4. Cost details of 43 bus system after one year of planning period.

Description	One DG	Two DG
C_{NLR}, (K$/yr)	16.33	22.90
$C_{DG,Gen}$, (K$/yr)	211.92	286.69
$C_{DG,O\&M}$, (K$/yr)	13.42	15.29
$C_{DG,Inv}$, (K$)	1761.04	1935.20

5. RESULT AND DISCUSSIONS

In this study, a MATLAB code is developed for the proposed algorithm using dual core Pentium processor, 2GB RAM laptop. The proposed algorithm is tested on a 43-bus practical distribution system which is a 11kV feeder with 43 buses and 42 branches, which is located in the region of a Settipalli distribution system, Tirupati DISCOM, AP, India and the data of the system is provided in the appendix. The real and reactive load of the system is 3497 kW and 3567 kVAR respectively. The type of DG considered is a solar PV type and the cost details are taken from the National Renewable Energy Limited (NREL) [11] and are shown in Table (10). The cost of power loss reduction is taken as $0.05/kWh and the cost of power generated by DG as $300/kW [6].

The present value of cost in the planning period is estimated by including inflation rate of 9% and interest rate of 12.5% in the NPV factor (γ), which is then multiplied with the varying costs.

5.1 Single DG placement

From Table (3), it is indicated that the fuzzy approach generates bus number 22 as optimal location for DG placement. When optimized the sizing of DG in this location using GSA it converges at 706.3952 kW. The real and reactive loss with DG reduces to 128.6523 kW and 82.1027 kVAR from 165.9362 kW and 105.8952 kVAR respectively. The objective function representing the saving of the system is tuned with sizing of the DG, such that the optimal DG size results in maximum saving for the system.

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For the first year in the planning period the cost saving through energy loss reduction is 16.33 K$, the cost of power generated by DG is 211.92 K$. The investment cost of DG which is DG rating converged by GSA as 1761.04 K$ and its O&M cost is 13.42 K$ and is shown in Table-4.

The load of the system is assumed to increase at 2% every year over the base load. In Table (5) the system parameters are indicated, where it can be observed that the investment cost of DG is given for each year for the related optimal rating of DG. But while calculating the maximization of system profit, the DG investment cost of the tenth year is considered so as to reflect the investment made right from the beginning of the first planning year. The penetration level of DG is indicated as percentage of the system load, where for the first year it is 20.2%.

In Table-6 the cost details for single placement is given for each planning year. The NPV factor (γ) column indicates the factor for each planning year. The cost details pose the present cost values for the particular year. Table (9) gives the consolidated results for single DG placement for the increasing load scenario, where it is observe that the maximum cost saving is resulted as 12.20 M$.

5.2 Multi DG placement

For multi DG placement analysis, two DG locations are considered. The buses 22 and 35 which got high placement indices are selected. GSA optimized the DG sizes for the locations at 250.3407 kW and 705.2986 kW respectively. The loss of the system with DG is 113.6443 kW and 72.5243 kVAR. For the first year the DG investment cost for the converged ratings is 1935.20 K$ and its maintenance is 15.29 K$. The saving cost through energy loss reduction and DG power generation is 22.90 K$, and 286.69 K$ respectively.

Table-7 indicates system parameter for the multi DG placements in increasing load scenario. Here it can be observe that the penetration level of DG shoots up when compared to the single DG placement. The cost details are indicated in Table-8.

The voltage profile of the system with single and multi DG placement for the first year of planning period is given in Figure-5. It is clearly visible that with multi DG placement, the voltage profile has a significant increase in magnitude at multiple places. Table-9 shows the cost saving of the system after the planning period. These costs are the cumulative sums over the planning period. The DG investment and its maintenance cost i.e. the expenses cost is lower for multi placement (3.86 M$) compared to the single placement (3.88 M$). The benefits of the system (which is the summation of the cost of net loss reduction and DG power generation) for multi placement is 19.99 M$ and for single placement it is 16.09 M$. The saving for the system with multi DG is 16.13 M$ which is the difference of the cumulative benefits and expenses and for single DG placement it is 12.20 M$.

Figure-6 shows the cost graph for the multi and single DG placement. The benefit curve of the multi-DG crosses the investment curve at 7.9 of the abscissa, indicating that the system has a payback period of 7.9 years for the investment made. For single DG placement the invested amount recovers at approximately 9.2 years' time.

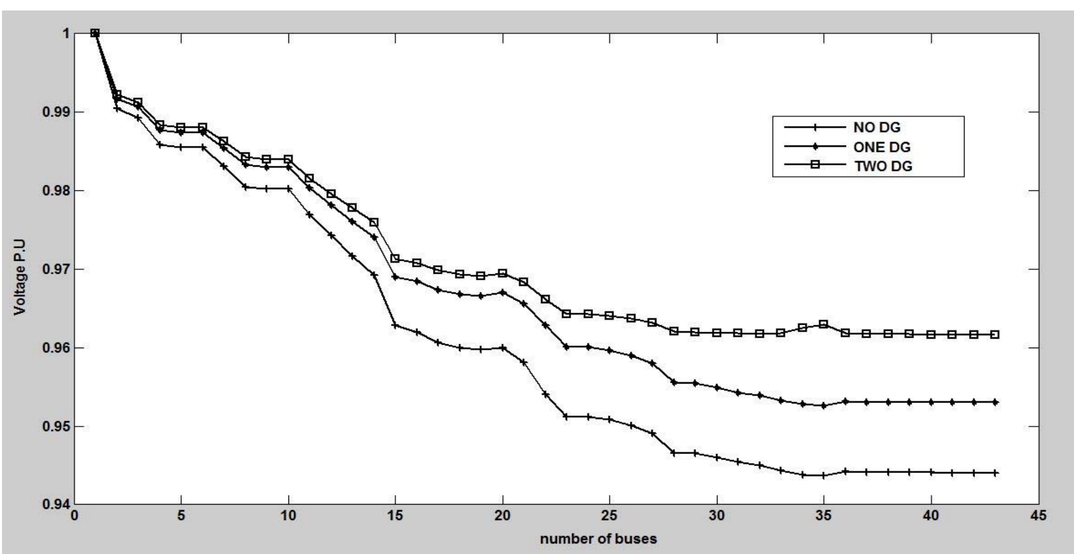

Figure-5. Voltage profile of 43 bus system for the first year.

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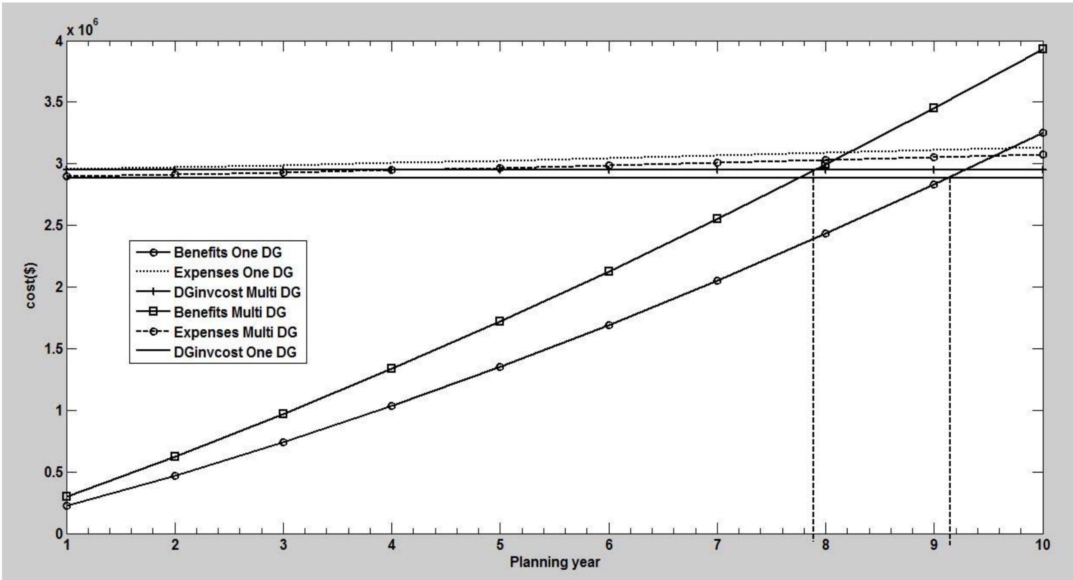

Figure-6. Cost graph for single and multi DG placement.

Table-5. System parameters for Single DG placement.

Planning year	**Load of the system**	**Real Load** (kW)	**Reactive Load** (kVAR)	**Real Losses** (kW)	**Reactive Losses** (kVAR)	**Real losses** (kW) **with DG**	**Reactive losses** (kVAR) **with DG**	**DG rating** (kW)	**Penetration level** (%)
1	1.0000	3497.000	3567.648	165.936	105.895	128.652	82.103	706.395	20.200
2	1.0200	3566.940	3639.001	172.974	110.386	132.374	84.478	758.891	21.276
3	1.0400	3636.880	3710.354	180.172	114.980	136.174	86.903	811.478	22.312
4	1.0600	3706.820	3781.707	187.532	119.677	140.051	89.377	864.154	23.313
5	1.0800	3776.760	3853.060	195.055	124.478	144.005	91.901	916.921	24.278
6	1.1000	3846.700	3924.413	202.742	129.383	148.038	94.474	969.780	25.211
7	1.1200	3916.640	3995.766	210.593	134.394	152.148	97.098	1022.729	26.112
8	1.1400	3986.580	4067.119	218.611	139.510	156.337	99.771	1075.771	26.985
9	1.1600	4056.520	4138.472	226.795	144.733	160.603	102.493	1128.905	27.829
10	1.1800	4126.460	4209.825	235.147	150.063	164.948	105.266	1182.131	28.648

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Table-6. Cost details for single DG placement.

Planning year	NPV factor	With 2% of load increasing every year	DG rating kW	Cost of Energy saving ($)	Cost of DG generated Power ($)	Cost of DG Operation and Maintenance ($)	Cost of DG Investment ($)
1	0.9689	1.0000	706.395	16330.361	211918.551	13421.507	1891916.212
2	1.9076	1.0200	758.891	17782.490	227667.414	14418.936	2023013.661
3	2.8172	1.0400	811.478	19271.150	243443.281	15418.070	2154336.326
4	3.6984	1.0600	864.154	20796.726	259246.249	16418.922	2285884.935
5	4.5522	1.0800	916.921	22359.616	275076.406	17421.515	2417660.694
6	5.3795	1.1000	969.780	23960.173	290933.898	18425.816	2549664.537
7	6.1810	1.1200	1022.729	25598.816	306818.837	19431.859	2681897.183
8	6.9576	1.1400	1075.771	27275.944	322731.310	20439.651	2814359.531
9	7.7101	1.1600	1128.905	28991.944	338671.424	21449.181	2947052.617
10	8.4391	1.1800	1182.131	30747.262	354639.304	22460.494	1891916.212

Table-7. System parameters for Multi DG placement.

Planning year	Load of the system	Real load (kW)	Reactive load (kVAR)	Real losses (kW)	Reactive losses (kVAR)	Real losses (kW) with	Reactive losses (kVAR) with DG	DG rating (kW) at		Penetration level (%)
								Bus 22	Bus 35	
1	1.0000	3497.000	3567.648	165.936	105.895	113.644	72.525	250.341	705.299	27.327
2	1.0200	3566.940	3639.001	172.974	110.386	117.177	74.779	286.898	720.453	28.241
3	1.0400	3636.880	3710.354	180.172	114.980	120.782	77.080	323.484	735.652	29.122
4	1.0600	3706.820	3781.707	187.532	119.677	124.460	79.427	360.101	750.896	29.972
5	1.0800	3776.760	3853.060	195.055	124.478	128.210	81.821	396.748	766.186	30.792
6	1.1000	3846.700	3924.413	202.742	129.383	132.033	84.261	433.424	781.522	31.584
7	1.1200	3916.640	3995.766	210.593	134.394	135.930	86.747	470.131	796.903	32.350
8	1.1400	3986.580	4067.119	218.611	139.510	139.899	89.280	506.867	812.331	33.091
9	1.1600	4056.520	4138.472	226.795	144.733	143.941	91.860	543.634	827.804	33.808
10	1.1800	4126.460	4209.825	235.147	150.063	148.056	94.486	580.431	843.325	34.503

Table-8. Cost Details for Multi DG placement.

Planning year	NPV factor	With 2% of load increasing every year	DG rating (kW) at		Cost of Energy saving ($)	Cost of DG generated Power ($)	Cost of DG Operation and Maintenance ($)	Cost of DG Investment ($)
			Bus 22	Bus 35				
1	0.9689	1.0000	250.341	705.299	22903.861	286691.769	15290.212	1935169.437
2	1.9076	1.0200	286.898	720.453	24439.021	302205.067	16117.623	2039884.200
3	2.8172	1.0400	323.484	735.652	26012.789	317740.855	16946.181	2144750.770
4	3.6984	1.0600	360.101	750.896	27625.631	333299.165	17775.955	2249769.363
5	4.5522	1.0800	396.748	766.186	29277.931	348880.075	18606.932	2354940.507
6	5.3795	1.1000	433.424	781.522	30970.131	364483.723	19439.148	2460265.130
7	6.1810	1.1200	470.131	796.903	32702.582	380110.108	20272.545	2565743.230
8	6.9576	1.1400	506.867	812.331	34475.742	395759.308	21107.165	2671375.332
9	7.7101	1.1600	543.634	827.804	36290.032	411431.454	21943.009	2777162.315
10	8.4391	1.1800	580.431	843.325	38145.888	427126.581	22780.088	2883104.420

Table-9. Cost details of 43-bus practical system after planning period.

Description	Single DG	Multi DG
C_{NLR}, (M$)	1.24	1.59
$C_{DG,Gen}$, (M$)	14.84	18.41
$C_{DG,O\&M}$, (M$)	0.94	0.98
$C_{DG,Inv}$, (M$)	2.94	2.88
Benefits, (M$)	16.09	19.99
Expenses, (M$)	3.88	3.86
C_{MS}, (M$)	12.20	16.13

6. CONCLUSIONS

In this paper, the cost saving of the system with increasing load scenario is studied for a planning period of 10 years. An objective function representing maximum saving of the system is developed. Fuzzy logic approach is implemented to generate best possible locations for DG placement. GSA algorithm has optimized the DG rating such that the value of objective function has increased. The system saving with multi DG is 16.13 M$ and has a payback period of 7.9 years. For single DG placement it is 12.20 M$ saving and 9.2 years' time required for the recovery of the invested amount. The voltage profile for multi DG placement is better when compared to that of single DG placement which as shown in figure (5). From the results it can be concluded that, compared to single DG placement, the system certainly has better technical and economic benefits for multi DG placement in increasing load scenario.

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APPENDIX

A. Cost details of DG

The cost data of DG for solar PV type is given in Table-10.

B. Data for practical distribution system

The data corresponding to the Indian 43-bus practical distribution system [12] is tabulated in Table-11. The values of the system parameters considered are: Base MVA = 100, Base kV = 11 kV, Line Resistance = *0.55* Ω/km, Line Reactance = *0.35* Ω/km, Power factor = 0.7 lagging and Diversity factor = 1.

Table-10. Cost details of DG for solar PV type.

Solar PV	**Mean installed cost**($/kW)	**Fixed O&M** ($/kW-yr)	**Variable O&M** ($/kWh)	**Life time** (yr)
PV <10 kW	$3,897	$21	N/A	33
PV 10-100 kW	$3,463	$19	N/A	33
PV 100-1,000 kW	$2,493	$19	N/A	33
PV 1-10 MW	$2,025	$16	N/A	33

Table-11. Line and load data of Indian 43-bus practical distribution system.

Line	**End buses of a line**		**Line**	**KVA load**
Number	**Bus X**	**Bus Y**	**Distance** (km)	**at Bus Y**
1	1	2	7.5	100
2	2	3	1	63
3	3	4	3	63
4	4	5	3.5	100
5	5	6	1	100
6	4	7	2.5	160
7	7	8	2.5	160
8	8	9	4.5	100
9	9	10	0.5	63
10	8	11	4	100
11	11	12	3	63
12	12	13	3	25
13	13	14	3	100
14	14	15	8	160
15	15	16	1	100
16	16	17	2	100
17	17	18	6.5	160
18	18	19	4.5	100
19	17	20	1	100
20	20	21	3.5	63
21	21	22	8	160
22	22	23	6	100
23	23	24	1	63
24	23	25	1	100
25	25	26	2	63
26	26	27	3	100
27	27	28	8	100
28	28	29	2.5	63
29	28	30	2.5	100
30	30	31	3	100
31	31	32	2.5	100
32	32	33	5	100
33	33	34	6.5	100
34	34	35	4	100
35	33	36	3	63
36	2	37	3	15
37	37	38	0.5	15
38	38	39	1.5	15
39	39	40	0.5	15
40	40	41	1	15
41	41	42	1	15
42	42	43	1	15