International Journal of Soft Computing 6 (4): 128-135, 2011
ISSN: 1816-9503

Optimal Location and Sizing of DG and Shunt Capacitors Using Differential Evolution

Jagadeesh Gunda and Nasim Ali Khan
Department of Electrical Engineering, N.I.T Durgapur, India

Abstract: Last few years, a number of factors have led to an increased interest in Distributed Generation (DG) scheme because placement of DG is the most effective method in reducing the power loss of the distribution networks to serve remote loads. Placement of shunt capacitors improves voltage profile but unable to serve remote load as it can provide only reactive power. So, combination of both gives productive solution. In this study, Differential Evaluation Algorithm (DEA) is utilized to find optimal location and size of both DGs and Shunt capacitors in radial distribution systems with an objective of minimizing line losses subjected to bus voltage limits. The performance of the proposed algorithm is implemented on Indian Electricity Board benchmark 25 Bus distribution system.

Key words: Distributed generators, capacitor allocation, voltage profile, differential evolutionary algorithm, location, India

INTRODUCTION

It has been seen that as much as 13% of total power generated is wasted in the form of losses at the distribution level (Song *et al*., 1997). The capacity of the radial lines is often limited, it is thus necessary to consider how future load additions will be served. Schmill (1965) developed his well-known 2/3 rule for the placement of one capacitor assuming a uniform load and a uniform distribution feeder. Baran and Wu (1989a, b) distinguished capacitor placement problem separately into a master problem and a slave problem. The master problem is used to determine the location of the capacitors while the slave problem is used to determine the type and size of the capacitors. Dura (1968) considered the capacitor sizes as discrete variables and employed dynamic programming to solve the problem. Grainger and Lee (1981) developed a nonlinear programming based method in which capacitor location and capacity were expressed as continuous variables. Chen *et al*. (1995) considered the mutual coupling effect of conductors to install capacitors in unbalanced distribution systems. Grainger and Civanlar (1985) formulated the capacitor placement and voltage regulators problem and proposed decoupled solution methodology for general distribution system. Baran and Wu (1989a, b) presented a method with mixed integer programming. Sundharajan and Pahwa (1994) proposed the genetic algorithm approach to determine the optimal placement of capacitors based on experiences in the selection of the probability parameters. When costs of building or up-grading transmission lines are weighed against the costs of distributed generation, it is easy to envision cases where distributed generation would be more cost effective. In addition to economic concerns, questions regarding power quality, reliability, storage and stability need to be addressed in the design and operation of distributed generation. Because of the unique power requirements of an industrial site, the distributed generation needs of such sites which are much different than those of residential, agricultural or urban sites.

The installation of DG units at inappropriate places can result in an increase in system losses and costs. In the last few years various techniques have been developed to find the optimal location and size of the DG. Teng *et al*. (2007) was used GA for finding the optimal placement, size and type of DGs in distribution networks to maximize the reliability. By Wang and Nehrir (2004) an analytical based method is proposed to find the optimal location of DG to minimize the line loss. Hedayati *et al*. (2008) employed another analytical method which is basedon the analysis of continuation power flow and the most sensitive bus to the voltage collapse, to allocate the DGs. A Kalman filter algorithm is employed by Lee and Park (2009) to minimize the line loss by determining the optimal location of DGs. By Jabr and Pal (2009), optimal location and size of DGs was found using the ordinal optimization approach. By Wang and Singh (2008), Reclosers along with DGs are optimally allocated to improve the reliability using Ant Colony System (ACS). Sookananta *et al*. (2010) proposed particle swarm

Corresponding Author: Jagadeesh Gunda, Department of Electrical Engineering, N.I.T Durgapur, India

optimization technique to determine the optimal location and sizing of DG with an objective of minimizing line losses.

Differential Evolutionary Algorithm (DEA) is a novel evolution algorithm as it employs real-coded variables and typically relies on mutation as the search operator (Storn, 1996; Storn and Price, 1995). More recently, DEA has evolved to share many features with CGA (Goldberg, 1989; Koridak *et al*., 2009). There are also a number of significant advantages when using DEA which were Ability to find the true global minimum regardless of the initial parameter values, Parallel processing nature and fast convergence; Capable of providing multiple solutions in a single run (Sum-Im *et al*., 2009). In this study, the researchers developed DEA to find optimal location and sizing of DG sets and Shunt capacitors with an objective of minimizing line losses while satisfying the voltage limits and voltage deviations at different buses.

PROBLEM FORMULATION

The problem of DG parceling and Capacitor allotment with their proper capacity is of great importance. The installation of both DG units and Shunt capacitors at non-optimal places can result in an increase in system losses and costs. For that reason, a power system planning engineer require an efficient and fast optimization method capable of indicating the best solution for a given distribution network. The selection of the best places for installation and the preferable size of the DG units and Shunt capacitor bank in large distribution systems is a complex discrete optimization problem. The optimal placement and sizing of DG and Shunt capacitor on the distribution network has been continuously studied in order to achieve different ends.

Power flow solution: The load flow solution is carried by the following set of recursive equations derived from the single line diagram shown in Fig. 1:

$$P_{i+1} = P_i - P_{Li+1} - R_{j,i+1}.\frac{P_i^2 + Q_i^2}{|V_i|^2} \tag{1}$$

$$Q_{i+1} = Q_i - Q_{Li+1} - X_{j,i+1}.\frac{P_i^2 + Q_i^2}{|V_i|^2} \tag{2}$$

$$V_{i+1}^2 = V_i^2 - 2(R_{j,i+1}.P_i + X_{j,i+1}.Q_i) + (R_{i,i+1}^2 + X_{i,i+1}^2).\frac{P_i^2 + Q_i^2}{|V_i|^2} \tag{3}$$

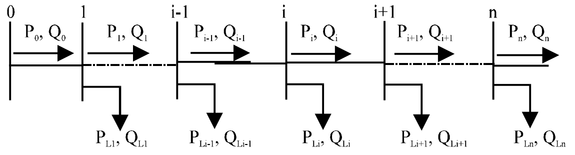

Fig. 1: Single-line diagram of a main feeder

Where:

P_i and Q_i = The real and reactive powers flowing out of bus i

P_{Li} and Q_{Li} = The real and reactive load powers at bus i

The resistance and reactance of the line section between buses i and i+1 are denoted by $R_{i,\ i+1}$ and $X_{i,\ i+1}$, respectively. The power loss of the line section connecting buses i and i+1 is computed as:

$$P_L = R_{i,i+1}.\frac{P_i^2 + Q_i^2}{|V_i|^2} \tag{4}$$

$$Q_L = R_{i,i+1}.\frac{P_i^2 + Q_i^2}{|V_i|^2} \tag{5}$$

The total power loss of the feeder P_{TL} may then be determined by summing up the losses of all line sections of the feeder which is given as:

$$\text{TPloss} = \sum_{i=0}^{n-1} P_L\,(i, i+1) \tag{6}$$

$$\text{TQloss} = \sum_{i=0}^{n-1} Q_L\,(i, i+1) \tag{7}$$

Where:

TPloss = Total active power loss in the system

TQloss = Total Reactive power loss in the system

In order to incorporate the proposed method recursive Eq. 1 and 2 are modified as (Abu-Mouti and El-Hawary, 2007):

$$P_{i+1} = P_i - P_{Li+1} - R_{j,i+1}.\frac{P_i^2 + Q_i^2}{|V_i|^2} + \mu_p.AP_{i+1} \tag{8}$$

$$Q_{i+1} = Q_i - Q_{Li+1} - X_{j,i+1}.\frac{P_i^2 + Q_i^2}{|V_i|^2} + \mu_q.RP_{i+1} \tag{9}$$

Where:

μ_p = Real power multiplier, set to zero when there is no active power source or set to 1 when there is active power source

μ_q = Reactive power multiplier, set to zero where there is no reactive power source or set to 1 when there is a reactive power source
AP_{i+1} = Active power magnitude injected at bus i+1
RP_{i+1} = Reactive power magnitude injected at bus i+1

Objective function: The installation of DG units should not result in an increase in the system losses and costs. So, the model described in this study explicitly assumes the multi-objective nature of the problem by considering minimization of active power loss as an objective function subjected to quality of service requirements of an acceptable voltage profile. The objective function is formulated as:

$$\text{Minimize (TPloss)}$$

$$\text{Subjected to } V_{min} \leq |Vi| \leq V_{max}$$

where, V_{min} and V_{max} are minimum and maximum values of bus voltage (Set to 0.985 and 1.0 in this study).

DIFFERENTIAL EVOLUTIONARY ALGORITHMS

DEA is an evolutionary computational algorithm that was originally introduced by Storn and Price (1995). The DEA optimisation process is carried out by applying the following three basic genetic operations; mutation, recombination (Also known as crossover) and selection. After the population is initialised, the operators of mutation, crossover and selection create the population of the next generation $pop^{(G+1)}$ by using the current population $pop^{(G)}$.

DEA optimization process

Initialization: In the first step of the DEA optimization process, the population of candidate solutions must be initialized. The initial population of candidate is generated within its corresponding feasible limits as follows:

$$X_j^{(G=0)} = x_{min} + (x_{max} - x_{min}).*\text{rand}(j,D) \quad j=1,2,...N_p \tag{10}$$

$$X = \left[X_1 X_2 ... X_j ... X_{N_p}\right], \quad j=1,2,...N_p \tag{11}$$

Where:
N_p = Number of population
D = Number of decision variables

In this study the researchers considered active and reactive power injected by DG and or Shunt capacitor as decision variables.

Mutation: The mutation operator generates mutant vectors (v_i^G) by perturbing a randomly selected vector (X_{r1}) with the difference of two other randomly selected vectors (X_{r2} and X_{r3}). DEA has several strategies to generate mutant vectors but in this study, the simplest and most popular DE method is used.

$$V_i^G = X_{r1}^G + F(X_{r2}^G - X_{r3}^G) \quad i=1,2,...,N_p \tag{12}$$

Vector indices r_1, r_2 and r_3 are randomly chosen where r_1, r_2 and r_3 belong to $\{1...N_p\}$ and $r_1 \neq r_2 \neq r_3 \neq i$. F is a user-defined constant known as the scaling mutation factor which is typically chosen from within the range [0, 1].

Crossover: Crossover operation helps to increase the diversity among the mutant parameter vectors and aids the algorithm to escape from local optima. At the generation G, the crossover operation creates trial vectors (U_i) by mixing the parameters of the mutant vectors (V_i) with the target vectors (Xi) according to a selected probability distribution:

$$U_i^{(G)} = u_{j,i}^{(G)} = \begin{cases} v_{j,i}^{(G)}, & \text{if } \text{rand}_j \leq CR \\ x_{j,i}^{(G)}, & \text{otherwise} \end{cases} \tag{13}$$

The crossover constant CR is a user-defined value (Known as the crossover probability) which is usually selected from within the range [0, 1].

Selection: The selection operator chooses the vectors that are going to compose the population in the next generation. This operator compares the fitness of the trial vector and the corresponding target vector and selects the one that provides the best solution and advance it into the next generation according to following equation:

$$X_i^{(G+1)} = \begin{cases} U_i^{(G)}, & \text{if } f(U_i^{(G)}) \leq f(X_i^{(G)}) \\ X_i^{(G)}, & \text{otherwise} \end{cases} \tag{14}$$

The overall optimization process is stopped whenever maximum number of generations is reached or other predetermined convergence criterion is satisfied.

IMPLEMENTATION OF DEA TO THE PROBLEM

In the problem the values of DG set and/or Shunt capacitors (AP and RP) are considered as decision variables. The step wise implementation of DEA to the problem is as follows:

1) Read the feeder data; set maximum number of capacitors N_C^{max} and maximum number of DG sets N_{DG}^{max}
2) Set the control parameters of DEA optimization process those are population size (N_p = 40) number of decision variables (D), scaling mutation factor (F = 0.7), Crossover probability (CR = 0.8) and maximum number of generations G^{max}. D = 1 if either DG set or shunt capacitor is present. D = 2 if both DG set and shunt capacitor are present
3) Generate initial population for the chosen decision variable (s) AP and/or RP
4) Loop
5) To place number of DG sets and/or number of Shunt Capacitors and their positions at which they have to be place can be obtained as follows: Let N_{bus} = Number of buses; N_C^G = Number of capacitors to be place at Gth iteration; N_{DG}^G = Number of DG sets to be place at Gth iteration; K = probability of getting 1's in a binary number where:

$$K = \frac{N_{DG}^G}{N_{bus}} \text{ or } \frac{N_G^G}{N_{bus}}$$

- Generate a binary numbers (μ_p and/or μ_q) with size N_{bus} and probability K
- The positions of non zeros in the number themselves represent the positions of DG sets or Shunt capacitors

6) Run the load flow
7) Compute Active power, Reactive power and Voltage profile using (5), (4) and (3), respectively
8) Calculate Total Active power loss (TPloss), Total Reactive power loss (TQloss) using (6) and (7)
9) Apply convergence criterion as If:

$$0.985 \le V_i \le 1.0$$

Print the result and STOP Else, GO to step 10

10) Increment generation counter by one i.e., G = G+1
11) Increase number of DG sets and shunt capacitors as follows If:

$$N_{DG}^G < N_{DG}^{max}$$

Then:

$$N_{DG}^G = N_{DG}^G + 1$$

If:

$$N_C^G < N_C^{max}$$

Then:

$$N_C^G = N_C^G + 1$$

12) Apply mutation, crossover, selection operations using Eq. 12-14, respectively
13) Modify the population
14) End loop

RESULTS AND DISCUSSION

The proposed algorithm is tested on 25-Bus Indian Radial system. The system data is available by Kumar and Selvan (2008). To demonstrate the effectiveness of the proposed algorithm, three different cases have been considered as follows:

- Case I: Placement of only DG sets
- Case II: Placement of only Shunt capacitors
- Case III: Placement of both DG and Shunt capacitors

Case I

Placement of only DG sets: In this case only DG sets are placed to improve the voltage profile as well as to decrease the system losses. The optimal location and values of DG sets are shown in Table 1. The values of voltage, real and reactive power loss at different buses are shown in Table 2-4, respectively. Voltage profile is shown in Fig. 2. It may be shown from Table 1 that total 23.7630 MW is needed to maintain voltage within the specified limits. From Table 5 it may be found that average voltage per bus is maintain at 0.9946 p.u. and voltage profile increased by 8.59% as compare to normal power flow. Active and Reactive power loss are shown in Table 3 and it may be observed that losses are reduced compare to normal power flow.

Table 1: Optimum location and sizing of DG set

Total DG sets	Optimum location	Optimum capacity (MW)
4	4	5.65
	5	6.62
	9	5.90
	10	5.57

Table 2: Voltage profile

Bus no	Normal power flow	Case-I	Case-II	Case-III
1	1	1	1	1
2	0.9875928	0.9993403	0.997893711	0.9998721
3	0.9697568	0.9988507	0.997002059	0.9997573
4	0.953892	0.998573	0.995961224	0.9997902
5	0.933108	0.9974602	0.993296637	0.9979329
6	0.9253891	0.9960335	0.992214918	0.995727
7	0.9187854	0.9956379	0.992087762	0.9945493
8	0.9061617	0.9954014	0.991568446	0.9927308
9	0.9050274	0.9956679	0.991741122	0.9923061
10	0.902822	0.9957888	0.992466634	0.9918206
11	0.895166	0.9931471	0.994682642	0.9909444
12	0.8943947	0.9924523	0.99413014	0.990248
13	0.8921998	0.9904758	0.993102631	0.9882671
14	0.891159	0.9895385	0.99287968	0.9873276
15	0.8939238	0.9941541	0.996630845	0.9928404
16	0.8930794	0.9955203	0.997894044	0.9943584
17	0.8928902	0.9974763	0.998563385	0.9964674
18	0.8961317	0.9930764	0.988316438	0.9931922
19	0.8914431	0.9923508	0.986371559	0.9933066
20	0.8907526	0.9924248	0.98602448	0.993548
21	0.8890437	0.9926431	0.985193715	0.9944444
22	0.9537334	0.9984215	0.996030405	0.9997111
23	0.9532356	0.997946	0.996263958	0.9992362
24	0.8852496	0.9874928	0.986719893	0.9904752
25	0.8846787	0.9869811	0.98662559	0.9899651

Table 3: Active power loss

Bus no	Normal power flow	Case-I	Case-II	Case-III
1	0	0	0	0
2	0.00431308450826893	0.00985775316826264	1.25954192929176e-005	1.03240552364151e-005
3	0.00575812916851156	0.0130000068376487	8.1210054420811e-005	1.5784493767749e-005
4	0.00508544169818087	0.010499982175199	7.62988699502276e-005	1.28544773901848e-005
5	0.00601434118559933	0.0105578850703629	0.000137821766997902	0.000117061186162628
6	0.00216947475356165	0.00358012293252325	0.000158780397146907	4.07651459134355e-005
7	0.00168026263581297	0.00346435853109864	4.88586201649391e-005	9.09940030368184e-007
8	0.00308028930414028	0.00595505400385806	5.7154590018109e-005	2.18980544111078e-005
9	0.000125589856049787	0.000331127180967943	2.10032541914283e-005	1.32619785278367e-005
10	0.000189037143458778	0.000627965490990826	1.38182230697273e-005	4.71773863170347e-006
11	0.000581487555258828	0.00180285353862222	2.3257845706156e-005	2.32397233267076e-006
12	3.96725585214158e-005	3.0641078602385e-005	3.23454921277163e-005	6.02435977783976e-006
13	5.41890904119196e-005	5.5337279223328e-005	4.41537302106678e-005	0.00017269581566351
14	1.65309481745402e-005	2.4142663554403e-005	1.34674883881648e-005	1.31620133507766e-005
15	3.05369969702287e-005	0.00036429255855194	6.05483446082639e-005	3.08835169326868e-005
16	1.39433450287908e-005	0.000156390959968152	7.33477533864772e-005	1.12360853197564e-005
17	8.02442825186996e-007	2.8180889442264e-005	0.000120511545831898	6.4659992850402e-007
18	0.00138778379116437	0.00163167906411525	2.27980026711631e-005	0.000166496945756762
19	0.00057665261552703	0.000582877615597914	4.94327735216825e-005	7.24368244493691e-005
20	6.45079638892869e-005	5.9536706469698e-005	2.22924717492934e-005	2.90845220044528e-006
21	8.55893503244739e-005	8.1230786729266e-005	4.99364991649961e-005	3.32581417053913e-005
22	5.1578443417923e-006	2.0749562833068e-005	5.50214681863696e-006	5.08599894002169e-006
23	8.72828368010422e-006	3.6636224232726e-005	7.94315467181146e-006	7.96739233883175e-006
24	0.000239418852211745	0.000566879330887925	0.000199165041380939	0.000191088365976834

Table 4: Reactive power loss

Bus no	Normal power flow	Case-I	Case-II	Case-III
1	0	0	0	0
2	0.00307835835492135	0.000316529552055947	0.0070357297122502	8.98967180906279e-006
3	0.00466792337927337	0.000556802264369997	0.0105386722097206	6.58342841171375e-005
4	0.00413475081691857	0.000508630382646045	0.00853707749556239	6.20352829862384e-005
5	0.00489051151847502	0.000550820751918158	0.00858505644325198	0.000112068623677965
6	0.00176342332909824	0.000146209437790235	0.00291004644782639	0.000129062140996417
7	0.00136577497670359	8.70091275297176e-005	0.00281594918035826	3.9713958636742e-005
8	0.00249708786255639	0.000188476992309962	0.0048275637791276	4.63333209746804e-005
9	0.00010047188483983	2.58000852386016e-005	0.000264901744774355	1.68026033531426e-005
10	0.000153655859923712	1.72773382738305e-005	0.000510431842944415	1.12319246342168e-005
11	0.000471392578129823	4.56071443637092e-005	0.00146151326864308	1.88543602524571e-005
12	3.22339537986504e-005	2.61638057696881e-005	2.48958763644358e-005	2.62807123537695e-005
13	4.39292892939295e-005	3.56342999631912e-005	4.48600876903778e-005	3.57939572907813e-005
14	1.34424258287631e-005	1.09024397233783e-005	1.96320235664809e-005	1.09513206288102e-005
15	2.47553255438654e-005	3.18449560279668e-005	0.000295319834132773	4.90845246957659e-005
16	1.13034050366731e-005	4.90697395884579e-005	0.000126780938214182	5.94605787453042e-005
17	6.50513650284925e-007	8.41259562926729e-005	2.28453077078623e-005	9.76946931543922e-005
18	0.00112850034263722	6.35279228208237e-005	0.00132682799341756	1.85385893607145e-005
19	0.000467888954947199	2.1163566166879e-005	0.000472939844684428	4.01091543165253e-005
20	5.18367566967484e-005	5.88215814648304e-006	4.78419962702921e-005	1.79135933699679e-005
21	6.92555048427041e-005	8.01792289766851e-006	6.57287281931446e-005	4.04066329121343e-005
22	4.18203595280457e-006	3.81586037329698e-006	1.68239698646498e-005	4.46120012321916e-006
23	7.06021168790653e-006	6.44175390170488e-006	2.96346347126936e-005	6.42512955675416e-006
24	0.00019449591192468	0.000156275900149608	0.000460513912725585	0.00016179505493846

Table 5: Total Voltage Deviation (TVD)

Normal power flow	Case-I	Case-II	Case-III
2.10032	0.133148	0.1763381	0.141184

Case-II

Placement of only Shunt capacitors: In this case only shunt capacitors are placed to improve the voltage profile as well as to reduce the system losses. The optimal location and values of shunt capacitors are shown in Table 6.

The values of voltage, real and reactive power loss are shown in Table 2-4, respectively. Voltage profile and Voltage deviation are shown in Fig. 1 and 2, respectively. From Table 6, it can be seen that total 15 number of capacitors with 41.076 MVAR is needed to maintain voltage within the specified limits.

From Table 5, it can be found that average voltage per bus is maintain at 0.9946 p.u and voltage profile increased by 8.40% as compare to normal power flow.

Active and reactive power loss is shown in Table 3 and it can found that losses are somewhat increased compare to normal power flow.

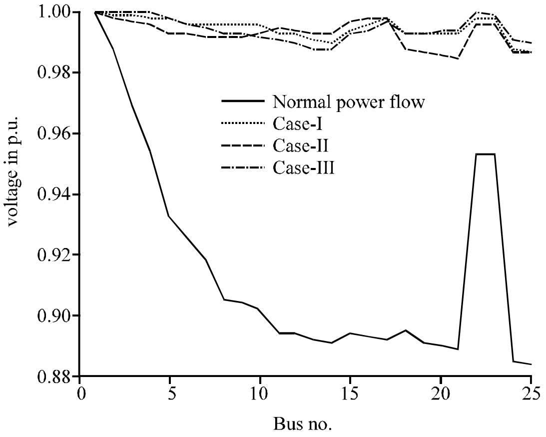

Fig. 2: Voltage profile

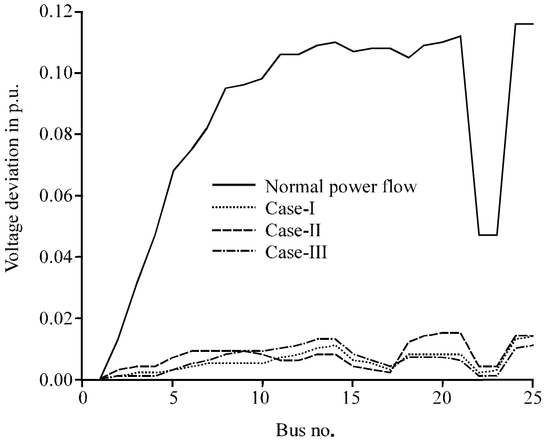

Fig. 3: Voltage deviation

Table 6: Optimum locations and sizing of capacitor

Total shunt capacitors	Optimum location	Optimum capacity (KVAR)
15	2	3459.23
	3	3889.14
	4	2756.51
	5	3310.52
	6	1219.99
	7	3508.46
	8	3211.91
	9	2193.47
	10	3078.25
	11	3529.64
	14	1547.25
	16	2395.92
	23	3001.85
	24	3973.72

Table 7: Optimum locations and sizing of capacitor

DG	Location	Size (MW)	Shunt capacitors	Location	Size (KVAR)
2	4	6.05	2	2	2407.79
	5	9.20	-	20	1065.421

Case-III

Placement of both DG and Shunt capacitors: In this case both DG and Shunt capacitors are placed to improve the voltage profile as well as to decrease the system losses. The optimal location and values of DG sets and shunt capacitors are shown in Table 6. The values of voltage, real and reactive power loss are shown in Table 2-4, respectively. Voltage profile and voltage deviation graph is shown in Fig. 1 and 2, respectively. It can be shown from Table 7 that total 15.2610 MW and 34.732 MVAR is needed to maintain voltage within the specified limits. From Table 5 it can be found that average voltage per bus is maintain at 0.9946 p.u. and voltage profile increased by 8.55% as compare to normal power flow. Active and reactive power loss shown in Table 3 and it is noticed that losses are reduced compare to normal power flow (Fig. 3-5). From Table 8 it may be found that the voltage profile in case-I is better than other cases as because of less voltage deviation per bus. From Table 5, it can also be found that the Total Voltage Deviation (TVD), Total active and reactive power loss is less compared to case-I but more than case-III.

Table 8: Voltage deviation

Bus no.	Normal power flow	Case-I	Case-II	Case-III
1	0	0	0	0
2	0.012407	0.00066	0.00210629	0.000128
3	0.030243	0.001149	0.00299794	0.000243
4	0.046108	0.001427	0.00403878	0.00021
5	0.066892	0.00254	0.00670336	0.002067
6	0.074611	0.003967	0.00778508	0.004273
7	0.081215	0.004362	0.00791224	0.005451
8	0.093838	0.004599	0.00843155	0.007269
9	0.094973	0.004332	0.00825888	0.007694
10	0.097178	0.004211	0.00753337	0.008179
11	0.104834	0.006853	0.00531736	0.009056
12	0.105605	0.007548	0.00586986	0.009752
13	0.1078	0.009524	0.00689737	0.011733
14	0.108841	0.010462	0.00712032	0.012672
15	0.106076	0.005846	0.00336916	0.00716
16	0.106921	0.00448	0.00210596	0.005642
17	0.10711	0.002524	0.00143662	0.003533
18	0.103868	0.006924	0.01168356	0.006808
19	0.108557	0.007649	0.01362844	0.006693
20	0.109247	0.007575	0.01397552	0.006452
21	0.110956	0.007357	0.01480629	0.005556
22	0.046267	0.001579	0.0039696	0.000289
23	0.046764	0.002054	0.00373604	0.000764
24	0.11475	0.012507	0.01328011	0.009525
25	0.115321	0.013019	0.01337441	0.010035

Table 9: Percentage increase in voltage

Voltage	Case-I	Case-II	Case-III
Average voltage per bus	0.9946	0.9929	0.9943
Percentage increase in average voltage (%)	8.5900	8.4000	8.5500

Although, Case-II is improving the voltage profile but the total voltage deviation, total active and reactive power loss is more compare to other two cases. From Table 9 and 10, it can be found that the average voltage

Table 10: Total active and reactive power losses

Power losses	Normal power flow	Case-I	Case-II	Case-III
TPloss	0.0315391894160385	0.00369701481586526	0.0633429879438778	0.00134704762410714
TQloss	0.0251878850213623	0.00295808082191974	0.0504636808229833	0.00109182023420778

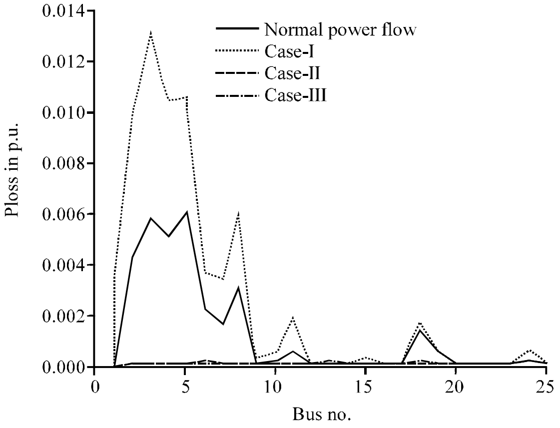

Fig. 4: Active power loss

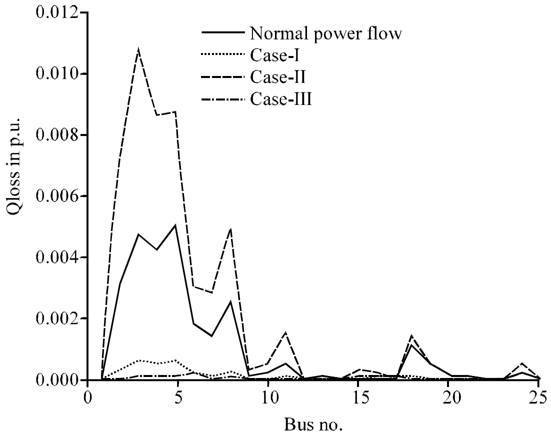

Fig. 5: Reactive power loss

per bus in case-III is almost equal to case-I and total active and reactive power losses are very less in case-III compared to other two cases. So, it may be concluded that case-III is superior to other cases in all respects.

CONCLUSION

In this study, optimal placement and sizing of both DG set and shunt capacitors in radial distribution network is solved using DEA. Minimization of line losses is considered as the objective function and voltage limits treated as inequality constraints. The proposed algorithm was examined on Indian 25-bus radial feeder. For the sake of comparison, different combinations of DG sets and shunt capacitors were considered. From the comparisons, it may be concluded that even though the presence of shunt capacitor builds up voltage but not able to reduce the system losses as much expected. On the contrary, the placement of DG not only improves the voltage but also reduces system losses. But the combination of DG along with Shunt capacitors significantly reduces system losses than the case only DG present and also improve the voltage profile near to the case when only DG present.

REFERENCES

Abu-Mouti, F.S. and M.E. El-Hawary, 2007. A new and fast power flow solution algorithm for radial distribution feeders including distributed generations. Proceedings of the IEEE International Conference on Systems, Man and Cybernetics, October 7-10, 2007, Montreal, Que, pp: 2668-2673.

Baran, M. and F. Wu, 1989. Optimal capacitor placement on radial distribution system. Inst. Electr. Electron. Eng. Trans. Power Delivery, 4: 725-734.

Baran, M.E. and F.F. Wu, 1989. Optimal sizing of capacitors placed on a radial distribution system. Inst. Electr. Electron. Eng. Trans. Power Delivery, 4: 335-343.

Chen, C.S., C.T. Hsu and Y.H. Yan, 1995. Optimal distribution feeder capacitor placement considering mutual coupling effect of conductors. IEEE Trans Power Delivery, 10: 987-994.

Dura, H., 1968. Optimum number, location and size of shunt capacitors in radial distribution feeders a dynamic programming approach. Inst. Elecr. Electron. Eng. Trans. Power Apparatus Syst., 87: 1769-1774.

Goldberg, D.E., 1989. Genetic Algorithm in Search, Optimization and Machine Learning. 1st Edn., Addison-Wesley, Reading, MA, USA.

Grainger, J.J. and S. Civanlar, 1985. Volt/var control on Distribution systems with lateral branches using shunt capacitors as Voltage regulators-Part I, II and III. IEEE Trans. Power Apparatus Syst., 104: 3278-3297.

Grainger, J.J. and S.H. Lee, 1981. Optimum size and location of shunt capacitors for reduction of losses on distribution feeders. IEEE Trans. Power Apparatus Systems, 100: 1105-1118.

Hedayati, H., S.A. Nabaviniaki and A. Akbarimajd, 2008. A method for placement of DG units in distribution networks. IEEE Trans. Power Delivery, 23: 1620-1628.

Jabr, R.A. and B.C. Pal, 2009. Ordinal optimization approach for locating and sizing of distributed generation. Electr. Comput. Commun. Eng. Dept. Notre Dame Univ. Zouk Mikhael Lebanon, 3: 713-723.

Koridak, L.A., M. Rahli and M. Younes, 2009. Hybrid optimization of the emission and economic dispatch by the genetic algorithm. Leonardo J. Sci., 8: 193-203.

Kumar, K.V. and M.P. Selvan, 2008. A simplified approach for load flow analysis of radial distribution network with embedded generation. Proceedings of the IEEE Region 10 Conference on TENCON 2008, November 19-21, 2008, Hyderabad, pp: 1-6.

Lee, S.H. and J.W. Park, 2009. Selection of optimal location and size of multiple distributed generators by using kalman filter algorithm. Inst. Electr. Electron. Eng. Trans. Power Syst., 24: 1393-1400.

Schmill, J.V., 1965. Optimum size and location of shunt capacitors on distribution feeders. Inst. Elect. Electron. Eng. Trans. Power Apparatus Syst., 84: 825-832.

Song, Y.H., G.S. Wang, A.T. Johns and P.Y. Wang, 1997. Distribution network reconfiguration for loss reduction using fuzzy controlled evolutionary programming. Proc. Gener. Transm. Distrib., 144: 345-350.

Sookananta, B., W. Kuanprab and S. Hanak, 2010. Determination of the optimal location and sizing of distributed generation using particle swarm optimization. Proceedings of the International Conference on Electrical Engineering/Electronics Computer Telecommunications and Information Technology, May 19-21, 2010, Chaing Mai, pp: 818-822.

Storn, R. and K. Price, 1995. Differential evolution: A simple and efficient adaptive scheme for global optimization over continuous spaces. Technical Report. International Computer Science Institute, Berkley, TR-95-012, California.

Storn, R., 1996. On the usage of differential evolution for function optimization. Proceedings of Biennial Conference of the North American Fuzzy Information Processing Society, June 19-22, 1996, Berkeley, CA, pp: 519-523.

Sum-Im, T., G.A. Taylor, M.R. Irving and Y.H. Song, 2009. Differential evolution algorithm for static and multistage transmission expansion planning. Gener. Transm. Distrib. IET., 3: 365-384.

Sundharajan, S. and A. Pahwa, 1994. Optimal selection of capacitors for radial distribution systems using genetic algorithm. Electron. Eng. Trans. Power Syst., 9: 1499-1507.

Teng, J.H., Y.H. Liu, C.Y. Chen and C.F. Chen, 2007. Value based distributed generator placements for service quality improvements. Int. J. Electr. Power Energy Syst., 29: 268-274.

Wang, C. and M.H. Nehrir, 2004. Analytical approaches for optimal placement of distributed generation sources in power systems. IEEE Trans. Power Syst., 19: 2068-2076.

Wang, L. and C. Singh, 2008. Reliability-constrained optimum placement of reclosers and distributed generators in distribution networks using an ant colony system algorithm. Inst. Electr. Electron. Eng. Trans. Systems, Man and Cybernetics-part C, 38: 757-764.