Optimal Capacitor Allocation for loss reduction in Distribution System Using Fuzzy and Plant Growth Simulation Algorithm

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Abstract—This paper presents a new and efficient approach for capacitor placement in radial distribution systems that determine the optimal locations and size of capacitor with an objective of improving the voltage profile and reduction of power loss. The solution methodology has two parts: in part one the loss sensitivity factors are used to select the candidate locations for the capacitor placement and in part two a new algorithm that employs Plant growth Simulation Algorithm (PGSA) is used to estimate the optimal size of capacitors at the optimal buses determined in part one. The main advantage of the proposed method is that it does not require any external control parameters. The other advantage is that it handles the objective function and the constraints separately, avoiding the trouble to determine the barrier factors. The proposed method is applied to 9 and 34 bus radial distribution systems. The solutions obtained by the proposed method are compared with other methods. The proposed method has outperformed the other methods in terms of the quality of solution.

Keywords—Distribution systems, Capacitor allocation, Loss reduction, Fuzzy, PGSA.

I. INTRODUCTION

THE loss minimization in distribution systems has assumed greater significance recently since the trend towards distribution automation will require the most efficient operating scenario for economic viability variations. Studies have indicated that as much as 13% of total power generated is wasted in the form of losses at the distribution level [1]. To reduce these losses, shunt capacitor banks are installed on distribution primary feeders. The advantages with the addition of shunt capacitors banks are to improve the power factor, feeder voltage profile, Power loss reduction and increases available capacity of feeders. Therefore it is important to find optimal location and sizes of capacitors in the system to achieve the above mentioned objectives.

Since, the optimal capacitor placement is a complicated combinatorial optimization problem, many different optimization techniques and algorithms have been proposed in the past. [2] developed a basic theory of optimal capacitor placement. He presented his well known 2/3 rule for the placement of one capacitor assuming a uniform load and a uniform distribution feeder. Duran et al [3] considered the capacitor sizes as discrete variables and employed dynamic programming to solve the problem. Grainger and Lee [4] developed a nonlinear programming based method in which capacitor location and capacity were expressed as continuous variables.

Grainger et al [5] formulated the capacitor placement and voltage regulators problem and proposed decoupled solution methodology for general distribution system. Baran and Wu [6], [7] presented a method with mixed integer programming. Sundharajan and Pahwa [8] proposed the genetic algorithm approach to determine the optimal placement of capacitors based on the mechanism of natural selection. In most of the methods mentioned above, the capacitors are often assumed as continuous variables. However, the commercially available capacitors are discrete. Selecting integer capacitor sizes closest to the optimal values found by the continuous variable approach may not guarantee an optimal solution [9]. Therefore the optimal capacitor placement should be viewed as an integer-programming problem, and discrete capacitors are considered in this paper. As a result, the possible solutions will become a very large number even for a medium-sized distribution system and makes the solution searching process become a heavy burden.

In this paper, Capacitor Placement and Sizing is done by Loss Sensitivity Factors and Plant Growth Simulation Algorithm (PGSA) respectively. The loss sensitivity factor is able to predict which bus will have the biggest loss reduction when a capacitor is placed. Therefore, these sensitive buses can serve as candidate locations for the capacitor placement. PGSA is used for estimation of required level of shunt capacitive compensation to improve the voltage profile of the system. The proposed method is tested on 9 and 34 bus radial distribution systems and results are very promising.

The remaining part of the paper is organized as follows: Section 2 gives the problem formulation; Section 3 gives the fuzzy reasoning approach; Sections 4 gives brief description of the plant growth simulation algorithm; Section 5 develops the test results and Section 6 gives conclusions.

II. PROBLEM FORMULATION

The objective of capacitor placement in the distribution system is to minimize the annual cost of the system, subjected to certain operating constraints and load pattern. For simplicity, the operation and maintenance cost of the capacitor placed in the distribution system is not taken into consideration. The three-phase system is considered as balanced and loads are assumed as time invariant.

Mathematically, the objective function of the problem is described as:

$$Minimize \quad f = Min. \quad (COST) \qquad (1)$$

where COST is the objective function which includes the cost of power loss and the capacitor placement.

The voltage magnitude at each bus must be maintained within its limits and is expressed as:

$$V_{min} \le |V_i| \le V_{max} \qquad (2)$$

where $|V_i|$ is the voltage magnitude of bus i, V_{min} and V_{max} are minimum and maximum permissible voltages limits, respectively.

The power flows are computed by the following set of simplified recursive equations derived from the single-line diagram depicted in Fig. 1.
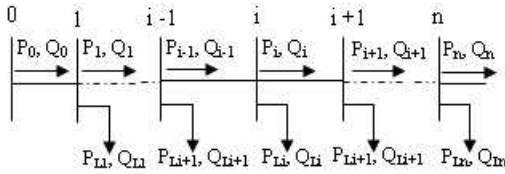

Fig. 1.   Single-line diagram of a main feeder

$$P_{i+1} = P_i - P_{Li+1} - R_{i,i+1} . \frac{P_i^2 + Q_i^2}{|V_i|^2} \qquad (3)$$

$$Q_{i+1} = Q_i - Q_{Li+1} - X_{i,i+1} . \frac{P_i^2 + Q_i^2}{|V_i|^2} \qquad (4)$$

$$|V_{i+1}|^2 = |V_i|^2 + \{R_{i,i+1}^2 + X_{i,i+1}^2\}\frac{P_i^2 + Q_i^2}{|V_i|^2} \\ -2\{R_{i,i+1} . P_i + X_{i,i+1} . Q_i\} \qquad (5)$$

where P_i and Q_i are the real and reactive powers flowing out of bus i, and P_{Li+1} and Q_{Li+1} are real and reactive load powers at bus $i+1$. The resistance and reactance of 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 $i+1$ may be computed as

$$P_{Loss}(i, i+1) = R_{i,i+1}\frac{(P_i^2 + Q_i^2)}{|V_i|^2} \qquad (6)$$

The total power loss in all feeders, $P_{T,Loss}$ may then be determined by summing up the losses of all line sections of the feeder, which is given as

$$P_{T,Loss} = \sum_{i=0}^{n-1} P_{Loss}(i, i+1) \qquad (7)$$

Considering the practical capacitors, there exists a finite number of standard sizes which are integer multiples of the smallest size Q_0^C. Besides, the cost per kVAr varies from one size to another. In general, capacitors of larger size have lower unit prices. The available capacitor size is usually limited to

$$Q_{max}^C = L . Q_0^C \qquad (8)$$

where L is an integer multiplier. Therefore, for each installation location, there are L capacitor sizes $\{Q_o^C, 2Q_o^C, 3Q_o^C, ..., LQ_o^C\}$ available. Given the annual installation cost for each compensated bus, the total cost due to capacitor placement and power loss change is computed by the formula:

$$COST = K_P P_{T,Loss} + \sum_{i=1}^{n}(K_{cf} + K_i^C Q_i^C) \qquad (9)$$

where n is number of candidate locations for capacitor placement, K_P is the equivalent annual cost per unit of power loss in Rs/(kW-year); K_{cf} is the fixed cost for the capacitor placement. The constant K_i^C is the annual capacitor installation cost, and, $i = 1, 2, ..., n$ are the indices of the buses selected for compensation. The bus reactive compensation power is limited to

$$Q_i^C \le \sum_{i=1}^{n} Q_{Li} \qquad (10)$$

where Q_i^C and Q_{Li} are the capacitive and inductive reactive powers at bus i respectively.

III. IDENTIFICATION OF OPTIMAL CAPACITOR LOCATIONS: FUZZY APPROACH

The candidate nodes for the placement of capacitors are determined using a fuzzy approach. The estimation of these candidate nodes basically helps in reduction of the search space for the optimization procedure. Two objectives are considered while designing a fuzzy logic for identifying the optimal capacitor locations. The two objectives are: (i) to minimize the real power loss and (ii) to maintain the voltage within the permissible limits. Voltages and power loss indices of distribution system are modeled by fuzzy membership functions. A fuzzy inference system (FIS) containing a set of rules is then used to determine the capacitor placement suitability of each node in the distribution system. Capacitors can be placed on the nodes with the highest suitability.

For the capacitor placement problem, an approximate reasoning is employed in the following manner: when losses and voltage levels of a distribution system are studied, an experienced planning engineer can choose locations for capacitor installations, which are probably highly suitable. For example, it is intuitive that a section in a distribution system with high losses and low voltage is highly ideal for placement of capacitors. Whereas a low loss section with good voltage is not ideal for capacitor placement. A set of fuzzy rules has been used to determine suitable capacitor locations in a distribution system.

In the first step, load flow solution for the original system is required to obtain the active power losses in the system. Again, load flow solutions are required to obtain the power loss reduction by compensating the total reactive load at every node of the distribution system. The loss reductions are then, linearly normalized into a [0, 1] range with the largest loss reduction having a value of 1 and the smallest one having a value of 0. Power Loss Index value for n^{th} node can be obtained using (11).

$$PLI_n = \frac{LR_{(n)} - LR_{(min)}}{LR_{(max)} - LR_{(min)}} \qquad (11)$$

where *LR* is Loss Reduction

These power loss reduction indices along with the p.u. nodal voltages are the inputs to the Fuzzy Inference System (FIS), which determines the node more suitable for capacitor installation. In this present work, Fuzzy Logic Toolbox in MATLAB7 is used for finding the capacitor suitability index.

Building Systems With The Fuzzy Logic Toolbox

The FIS Editor handles the high level issues for the system namely the number of input and output variables used and their names. In this paper, two input and one output variables are selected. Input variable 1 is power loss index (PLI) and Input variable 2 is the per unit nodal voltage (V). Output variable is capacitor suitability index (CSI). Power Loss Index range varies from 0 to 1, p.u. nodal voltage range varies from 0.9 to 1.1 and Capacitor suitability index range varies from 0 to 1.

The Membership Function Editor is used to define the shapes of all the membership functions associated with each variable. In this present work, five membership functions are selected for PLI. They are **L**, **LM**, **M**, **HM** and **H**. All the five membership functions are triangular as shown in Fig 2.
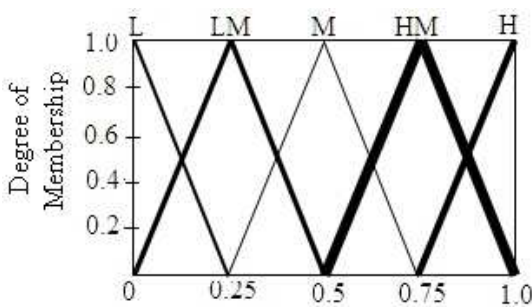

Fig. 2.   Membership function plot for Power Loss Index (PLI)

Five membership functions are selected for Voltage. They are **L**, **LN**, **N**, **HN** and **H**. These membership functions are trapezoidal and triangular as shown in Fig. 3.
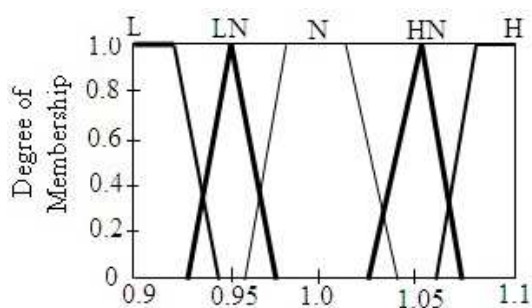

Fig. 3.   Membership function plot for p.u node voltage

Five membership functions are selected for CSI. They are **L**, **LM**, **M**, **HM** and **H**. These five membership functions are also triangular as shown in Fig. 4.
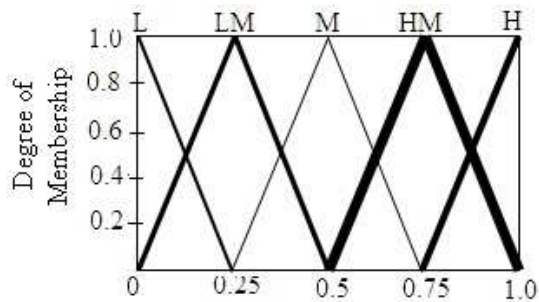

Fig. 4.   Membership function plot for Capacitor Suitability Index (C.S.I.)

The Rule Editor is for editing the list of rules that defines the behavior of the system. Constructing rules using the graphical Rule Editor interface is fairly self-evident. Based on the descriptions of the input and output variables defined with the FIS Editor, the Rule Editor allows us to construct the rule statements automatically, by clicking on and selecting one item in each input variable box, one item in each output box and one connection item. Choosing none as one of the variable qualities will exclude that variable from a given rule. Choosing not under any variable name will negate the associated quality. Rules may be changed, deleted or added, by clicking on the appropriate button.

For the capacitor allocation problem, rules are defined to determine the suitability of a node for capacitor installation. Such rules are expressed in the following form:

IF premise (antecedent), **THEN conclusion** (consequent).

For determining the suitability of capacitor placement at a particular node, a set of multiple-antecedent fuzzy rules has been established. The inputs to the rules are the voltage and power loss indices and the output is the suitability of capacitor placement. The rules are summarized in the fuzzy decision matrix in Table I. In the present work 25 rules are constructed. For Example:

If **PLI** is **H** and Voltage is **L** then **CSI** is **H**

If **PLI** is **M** and Voltage is **N** then **CSI** is **LM**

If **PLI** is **H** and Voltage is **H** then **CSI** is **LM**

The Rule Viewer is a MATLAB-based display of the fuzzy inference diagram. Used as a diagnostic, it can show which rules are active, or how individual membership function shapes are influencing the results. Surface Viewer can display how one of the outputs depends on any one or two of the inputs - that is, it generates and plots an output surface map of the system. Finally, to save the current file uses the commands **Export to workspace** and **Export to disk**. By calling this file in the main program, the CSI values corresponding to each bus can be obtained. Thereby, we can find the nodes suitable for capacitor installation. The sizing of Capacitors at buses done by using Plant Growth Simulation Algorithm.

TABLE I
FUZZY DECISION MATRIX FOR DETERMINING THE OPTIMAL CAPACITOR LOCATIONS

AND		Voltage				
		LL	LN	NN	HN	HH
PLI	L	LM	LM	L	L	L
	M	HM	M	LM	L	L
	HM	HM	HM	M	LM	L
	H	H	HM	M	LM	LM

IV. PLANT GROWTH SIMULATION ALGORITHM (PGSA)

The plant growth simulation algorithm [10] is based on the plant growth process, where a plant's trunk grows from its root; some branches will grow from the nodes on the trunk; and then some new branches will grow from the nodes on the branches. Such process is repeated, until a plant is formed. Based on an analogy with the plant growth process, an algorithm can be specified where the system to be optimized first "grows" beginning at the root of a plant and then "grows" branches continually until the optimal solution is found. By simulating the growth process of plant phototropism, a probability model is established. In the model, a function $g(Y)$ is introduced for describing the environment of the node Y on a plant. The smaller the value of $g(Y)$, the better environment of the node for growing a new branch. The outline of the model is as follows: A plant grows a trunk M, from its root B_o. Assuming that there are k nodes $B_{M1}, B_{M2}, B_{M3}, ..., B_{Mk}$ which have better environment than the root on the trunk M. This means that the function $g(Y)$ of the nodes that satisfy $g_{(BMi)} < g_{(Bo)}$ then morphactin concentrations $C_{M1}, C_{M2}, ., C_{Mk}$ of nodes $B_{M1}, B_{M2}, B_{M3}, .., B_{Mk}$ are calculated using

$$C_{Mi} = \frac{g_{Bo} - g_{Mi}}{\sum_{i=1}^{k} g_{Bo} - g_{Mi}} \qquad (i = 1, 2, ...k) \qquad (12)$$

The significance of (12) is that the morphactin concentration of a node is not only dependent on its environmental information but also depends on the environmental information of the other nodes in the plant, which really describes the relationship between the morphactin concentration and the environment. From (12), we can derive $\sum_{i=1}^{k} C_{Mi} = 1$, which means that the morphactin concentrations $C_{M1}, C_{M2}, ., C_{Mk}$ of nodes $B_{M1}, B_{M2}, B_{M3}, .., B_{Mk}$ respectively form a state space shown in Fig. 5. Selecting a random number β in the
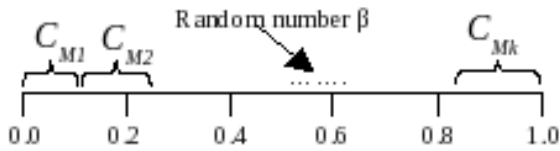

Fig. 5. Morphactin concentration state space

interval [0, 1], β is like ball thrown to the interval [0, 1] and will drop into one of $C_{M1}, C_{M2}, ., C_{Mk}$ in Fig. 5, then the corresponding node that called the preferential growth node, will take priority of growing a new branch in the next step. In other words, B_{MT} will take priority of growing a new branch if the selected β satisfies $0 \leq \beta \leq \sum_{i=1}^{T} C_{Mi}(T = 1)$ or $\sum_{i=0}^{T-1} C_{Mi} < \beta \leq \sum_{i=1}^{T} C_{Mi}(T = 1, 2, 3..., k)$. For example, if random number β drops into C_{M2}, which means $\sum_{i=1}^{1} C_{Mi} < \beta \leq \sum_{i=1}^{2} C_{Mi}$ then the node B_{M2} will grow a new branch m. Assume there are q nodes $B_{m1}, B_{m2}, B_{m3}, .., B_{mq}$, which have a better environment than the root B_0, on the branch m, and their corresponding morphactin concentrations are $C_{m1}, C_{m2}, C_{m3}, .., C_{mq}$. Now, the morphactin concentrations of the nodes on branch m and the morphactin concentrations of the nodes except B_{M2} (the morphactin concentration of the node B_{M2} becomes zero after growing the branch m) on trunk M have to be recalculated after growing the branch m. The calculation can be done using (13), which is deduced from (12) by adding the related terms of the nodes on branch m and abandoning the related terms of the node B_{M2}.

$$\begin{cases} C_{Mi} = \dfrac{g(B_o) - g(B_{Mi})}{\Delta_1 + \Delta_2} & (i = 1, ...k, i \neq 2) \\ \\ C_{mj} = \dfrac{g(B_o) - g(B_{mj})}{\Delta_1 + \Delta_2} & (j = 1, 2, 3, ...q) \end{cases}$$
$$(13)$$

where

$$\Delta_1 = \sum_{i=1, i \neq 2}^{k} (g(B_o) - g(B_{Mi}))$$

and $\Delta_2 = \sum_{j=1}^{q} (g(B_o) - g(B_{mj}))$.

We can also derive from (13),

$$\sum_{i=1, i \neq 2}^{k} C_{Mi} + \sum_{j=1}^{q} C_{mj} = 1.$$

Now, the morphactin concentrations of the nodes (except B_{M2}) on trunk M and branch m will form a new state space (more nodes will be introduced in Fig. 5). A new preferential growth node, on which a new branch will grow in the next iteration, can be obtained. This process is repeated until there is no new branch to grow, and then a plant is formed. From the mathematical point of view, the nodes on a plant can express the possible solutions; $g(Y)$ can express the objective function; the length of the trunk and the branch can express the search domain of possible solutions; the root of a plant can express the initial solution; the preferential growth node corresponds to the basis point of the next searching process. This way, the growth process of plant phototropism can be applied to solve the problem of integer programming.

PGSA Algorithm for Capacitor Placement

Complete algorithm of the proposed PGSA for capacitor placement is as follows:

1. input the system data such as line and load details of the distribution system, constraints (limits);

2. form the search domain with the range of capacitor ratings (kVAr ratings) available which corresponds to the length of trunk and branch of a plant;

3. give the initial solution X_0, a vector, which corresponds to the root of a plant, and calculate the initial value of objective function (power loss);

4. let the initial value of the basis point be X_b, which corresponds to the initial preferential growth node of a plant, and the initial value of optimization X_{best} equals to X_o, and let F_{best} that is used to save the objective function value of the best solution X_{best} equals to $f(X_o)$
    i.e., $X_b = X_{best} = X_o$ and $F_{best} = f(X_o)$;

5. identify the candidate buses for capacitor placement using Loss Sensitivity Factors;

6. initialize iteration count, $i = 1$;

7. for $j = n$ to m (with step size 1), where m is the minimum available size and n is maximum available size;

8. search for new feasible solutions: place kVAr at sensitive nodes in a sequence starting from basis point $X_b = [X_{1b}, X_{2b}, ...X_{ib}, ...X_{nb}]$, where X_b corresponds to the initial kVAr;

9. for each solution X_b in step 8, calculate the nodes voltages of the buses;

10. if the node voltage constraints are satisfied go to step 11; otherwise abandon the possible solution X_b and goto step 12;

11. calculate power loss $f(X_b)$ for each solution of X_b in step 8 and compare with $f(X_o)$. If $f(X_b) < f(X_o)$, save the feasible solutions ; Otherwise goto step 12;

12. if $i \geq N_{max}$ go to step 16; Otherwise goto step 14, where N_{max} is the maximum iteration count;

13. calculate the probabilities $C_1, C_2, ., C_k$ of feasible solutions $X_1, X_2, ., X_k$, using (12), which correspond to determining the morphactin concentration of the nodes of a plant;

14. calculate the accumulating probabilities $\sum C_1, \sum C_2, ..., \sum C_k$ of the solutions $X_1, X_2, ., X_k$. Select a random number β from the interval [0 1], β must belong to one of the intervals $[0, \sum C_1], (\sum C_1, \sum C_2], ..., (\sum C_{k-1}, \sum C_k]$, which is equal to the upper limit of the corresponding interval. This will be the new basis point X_b for the next iteration, which corresponds to the new preferential growth node of the plant for next step;

15. increment i by 1 and return to step 6;

16. output the results and stop.

V. RESULTS

The proposed method has been programmed using MAT-LAB and run on a Pentium IV, 3-GHz personal computer with 0.99 GB RAM. The effectiveness of the proposed method for loss reduction by capacitor placement is tested on 9 and 34 bus radial distribution systems. The results obtained in these methods are explained in the following sections.

A. Test case 1

9 - bus system: The first test case for the proposed method is a 10-bus, single feeder, radial distribution system [9]. This system has zero laterals. The rated line voltage of the system is 23 kV. The details of the feeder and the load characteristics are given in [9]. For this test feeder, KP is selected is selected to be 168 $/(kW-year) [9]. Only fixed capacitors are used in the analysis and the marginal cost of capacitors given [11] are used to compute the total annual cost. The fixed cost of the capacitor, Kcf is selected as $1000 [12] with a life expectancy of ten years (the maintenance and running costs are neglected). The substation voltage (bus 1) is considered as 1.0 p.u. The limit of voltage magnitude is taken between 0.90 to 1.10 p.u.

The method of sensitive analysis is used to select the candidate installation locations of the capacitors to reduce the search space. The buses are ordered according to their sensitivity value (i.e., bus 6, 5, 9, 10, 8 and 7). Top four buses are selected as optimal candidate locations and then amount of kVAR to be injected in the selected buses is optimized by PGSA. Using this method, the capacitors of rating 1200, 1200, 200, 407 kVAR are placed at the optimal candidate locations 6, 5, 9, and 10 respectively. The initial power loss is 783.77 kW and it is reduced to 694.93 kW after capacitor placement using the proposed method. The results of the proposed method are shown in Table II. Table II also shows the comparison of results with Fuzzy reasoning [13] and Particle Swarm Optimization (PSO) [14]. The minimum and maximum voltages before capacitor placement are 0.8375 p.u (bus 10) and 0.9929 p.u (bus 2) and these are improved to 0.901 p.u (bus10) and 0.9991 p.u (bus2) after capacitors placement. From Table II, it is observed that the power loss obtained with the proposed method is less than the Fuzzy reasoning [13] and PSO [14]. The optimal candidate locations are the same with all methods but the total kVAr injected by the proposed method is less than the other two. The selection of the allowable consecutive iterative number Nmax depends highly on the solved problem. The Nmax value is tried from 2 to 5. All of the results converge to the same optimal solution with Nmax greater than 4. The CPU time needed to get optimal solution is 0.6 seconds.

B. Test case 2

34 - bus system: The second test case for the proposed method is a 34-bus radial distribution system [15]. This system

TABLE II
SIMULATION RESULTS OF 9-BUS SYSTEM

item	Uncompe -nsated	Compensated		
		Fuzzy [13]	PSO [14]	Proposed
Total losses (kW)	783.77	704.883	696.21	694.93
Loss reduction (%)	—	10.065	11.17	11.33
Optimal locations and Size in kVAR	—	4 1050 5 1050 6 1950 10 900	6 1174 5 1182 9 264 10 566	5 1200 4 1200 8 200 9 407
Total kVAr		4950	3186	3007
Annual Cost ($/year)	131,674	119,420	118,582	118,340
Net Savings ($/year)	—	12,255	13,091	13,334
% Saving	—	9.31	9.94	10.13

has a main feeder and four laterals (sub-feeders). The single line diagram is shown in Fig. 6. The line and load data of the feeders are taken from the reference [15]. The rated line voltage of the system is 11 kV. Similar to test case 1, the sensitive analysis method is used to select the candidate installation locations of the capacitor to reduce the search space. The buses are ordered according to their sensitivity value as 19, 22, 20, 21, 23, 24, 25, 26, and 27. Top three buses are selected as optimal candidate locations and the amount of kVAr injected are 1200, 639, and 200 kVAr respectively. The constants K_P, K_C^i, and K_{cf} are same as in test case 1. The power loss before and after capacitor placement are 221.67 and 161.07 kW. The minimum and maximum voltages before capacitor placement are 0.9417 p.u (bus 27) and 0.9941 p.u (bus 2) and are improved to 09731 p. and 1.000 p.u after capacitor placement respectively at the buses 27 and 2. The N_{max} value is tried from 2 to 80. All of the results converge to the same optimal solution with N_{max} greater than 8.
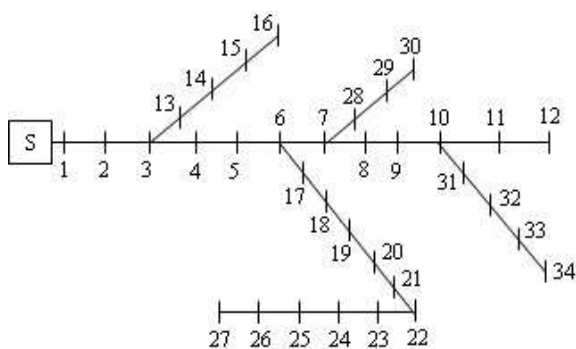

Fig. 6.   Radial 34-bus system before and after capacitor allocation

The results of the proposed method are compared with the results of PSO method [14] and Heuristic based method [15] and is shown inTable III. The implementation shows that the sub-feeder connected to node 6 of main feeder only need the compensation. From the results shown inTable III, it is observed that the optimal candidate installation locations are three for the proposed and PSO methods [14], but it is four for the Heuristic method [15]. The power loss and net annual savings obtained with proposed method are less than PSO methods and Heuristic based. The CPU time needed by the proposed method is 11 sec.

TABLE III
SIMULATION RESULTS OF 34-BUS SYSTEM

item	Uncompe -nsated	Compensated		
		Heuristic [15]	PSO [14]	Proposed
Total losses (kW)	221.67	168.47	168.8	161.07
Loss reduction (%)	—	23.999	23.850	27.337
Optimal locations and Size in kVAR	—	26 1400 11 750 17 300 4 250	12 781 22 803 20 479 – —	19 1200 22 639 20 200 – —
Total kVAr		2700	2063	2039
Annual Cost ($/year)	37,241	33,182	29,936	28,484
Net Savings ($/year)	—	4,089	7,306	8,756

VI. CONCLUSION

A new and efficient approach that employs loss sensitivity factors and PGSA for capacitor placement in the distribution system has been proposed. The loss sensitivity factors are used to determine the candidate locations of the buses required for compensation. The PGSA is used to estimate the required level of shunt capacitive compensation at the optimal candidate locations to enhance the voltage profile the system and reduce the active power loss. The simulation results based on 9 and 34 bus systems have produced the best solutions that have been found using a number of approaches available in the literature. The advantages of the proposed method are: 1) it handles the objective function and the constraints separately, avoiding the trouble to determine the barrier factors; 2) the proposed approach does not require any external parameters; 3) the proposed approach has a guiding search direction that continuously changes as the change of the objective function. This method places the capacitors at less number of locations with optimum size and offers much net annual saving in initial investment.

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