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Reduction in Power Losses in Distribution Lines using Bionic Random Search Plant Growth Simulation Algorithm

Tanuj Manglani[1], Y.S.Shishodia[2]

Assistant Professor, Department of Electrical Engineering, YIT, Jaipur, India

Pro. VC, JaganNath University, Jaipur, India

E-mail: idtanuj@gmail.com

Abstract **- To reduce the losses in distribution systems, bionic random search plant growth simulation algorithm (PGSA) has been proposed using optimal capacitor placement. The main advantage of the proposed method is that it does not require any external control parameters. The proposed method is implemented on IEEE 34 bus radial distribution system. The solutions obtained by PGSA give better results than fuzzy logic method.**

Index Terms **- Capacitor placement, capacitor sizing, optimal capacitor allocation, distribution system, power loss reduction, PGSA, Random search algorithm, Bionic search.**

I. INTRODUCTION

In the present scenario of energy crisis, saving of the power has become a major issue. Studies have indicated that 13% of total power is wasted in the form of losses at the distribution level [1]. The reduction of losses in the power networks is much more beneficial than the increase of generating capacities. Losses can be reduced by connecting capacitors in shunt to locally supply a considerable portion of the reactive power demanded by the consumers and thereby reducing the reactive component of branch currents [2]. Therefore, it is important to find optimal location and sizes of capacitors in the system to reduce power losses. Various optimization techniques and algorithms have been proposed in the past to reduce the power losses such as algorithm based on analytical methods [3-4], numerical programming methods [5-6], heuristics methods [7-8], genetic algorithm [9-11], simulated annealing [12-13],fuzzy logic [14-15],PSO[16-17] and ant colony algorithm [18].

In this paper, power losses will be reduced by using capacitor placement with the help of Plant Growth Simulation Algorithm (PGSA). The proposed method is tested on 34 bus radial distribution systems.

II. PROBLEM FORMULATION

The objective of the capacitor placement in the distribution system is to minimize the total annual power losses in such a way that the total annual cost of the system gets reduced under certain operating constraints. Newton Raphson method is used to calculate the total power loss of the system under study. The three-phase system is considered as balanced and the loads are assumed as time invariant. The cost of the operation and maintenance of the capacitor placed in the system are assumed to be neglected. The largest capacitor size can not be more than total reactive load at a particular bus [19].Mathematically, the objective function [20] of the problem is the cost which includes the cost equivalent to reduction of power loss in the system and the cost of capacitors placement which is to be minimized under certain constraints as;

Minimize

Objective function:

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

Subject to

Voltage limit: $V_{min,i} \leq V_i \leq V_{max,i}$ (2)

Capacitor size limit: $Q_i^c \leq \sum_{i=1}^{n} Q_{Li}$ (3)

Here, n is the number of buses , Kp is the equivalent annual cost per unit of power loss in \$/kW/year, K_i^c is the annual capacitor installation cost \$/kVAr, V_i is the voltage magnitude of bus i, $V_{min,i}$ *and* $V_{max,i}$ are minimum and maximum voltage limits of i^{th} bus respectively, Q_i^c is the reactive power compensated at bus i and and Q_{Li} is the reactive load power at bus i .

III. IDENTIFICATION OF OPTIMAL LOCATION

Optimal locations for capacitor placements are the selected buses that can be determined using Loss Sensitivity Factors. The estimation of these buses helps in reduction of the search space for the optimization procedure. A distribution line with an impedance $R+jX$ and a load of $P_{eff} + jQ_{eff}$ connected between 'p' and 'q' buses is given below Fig. 1.

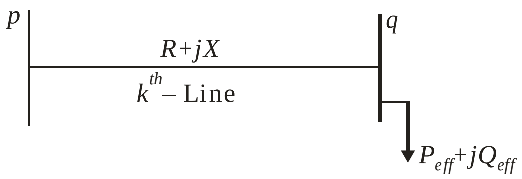

Fig. 1 Distribution Line with p and q Buses

Active power loss in the K^{th} line is given by $\left[I_k^2\right] * R[k]$ which can be expressed as,

$$P_{lineloss}[q] = \frac{(P_{eff}^2[q]+Q_{eff}^2[q]R[k])}{(V[q])*(V[q])} \quad (4)$$

Where, $Peff\ [q]$ & $Qeff\ [q]$ are the total effective active and reactive power respectively supplied beyond the node q.

Now, the Loss Sensitivity Factors [21] can be given by

$$\frac{\partial P_{lineloss}}{\partial Q_{eff}} = \frac{(2 * Q_{eff}[q] * R[k])}{(V[q]) * (V[q])} \quad (5)$$

Loss Sensitivity Factors ($\partial P_{lineloss} / \partial Q_{eff}$) are calculated from load flow analysis of the given system and the values are arranged in descending order for all the lines of the system. The descending order will decide the sequence in which the buses are to be considered for compensation [22]. If the nominal voltage (i.e. $V[i]$ / 0.95) at a bus in the sequence list is greater than 1.01then such bus needs no compensation.

IV. PLANT GROWTH SIMULATION ALGORITHM

Plant Growth Simulation Algorithm (PGSA) is a new type of intelligent optimization algorithm which is based on a computer system (namely L-systems) proposed by A. Lindenmayer and P.Prusinkiewicz in the 1990s. L-system is used in the fractal domain and the computer graphics to simulate the plant growing and branching process. When plant outgrows, the main drive to promote its growth impetus comes from the sunlight, the auxin concentrations in plant are changed with photosynthesis, and the point which has received sufficient sunlight with more concentrations will grow prior. By using plant growth simulation algorithm to solve optimization problems is actually a simulation process of plant outgrowing to the whole space. The point which can outgrow a new branch in the plant is called growing point, the more auxin concentration of the growing point, the more growing opportunities it gets. The auxin concentration of plant is mainly decided by phototropic, it will be reassigned among each growing points if the environment location is changed. Tong Li *et al.* [23] analyzed the probability growth model of simulating the plants phototropic, and gives out auxin concentration calculating formulas of the stems and branches.

Assuming a plant grows a trunk M from its root and there are k initial growing points called nodes $N_{M1}, N_{M2}, N_{M3}.....N_{Mk}$ that have better environment than the root N_0 on the trunk M.

The auxin concentration $S_{M1}, S_{M2}..............S_{Mk}$ of the nodes $N_{M1}, N_{M2}.....N_{Mk}$ can be calculated by

$$S_{Mi} = \frac{f(N_0) - f(N_{Mi})}{\sum_{i=1}^{k}\left[f(N_0) - f(N_{Mi})\right]} \quad (6)$$

The auxin concentration of the growing point can be more if the function of the nodes $N_{M1}, N_{M2}, N_{M3}.....N_{Mk}$ and N_0 satisfy $f(N_{Mi}) < f(N_o)$ for i=1,2,3….k. From (6), it can be calculated that summation of all concentration is equal to unity, which means that the auxin concentrations $S_{M1}, S_{M2}..............S_{Mk}$ of the corresponding nodes $N_{M1}, N_{M2}.....N_{Mk}$ form a state space shown in Fig 2.

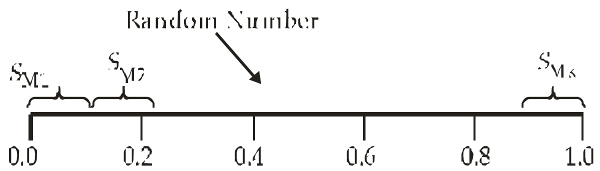

Fig. 2 Auxin Concentration State Space

Now randomly generates a number within [0, 1] and drop into one of S_{M1},S_{M2}…………..S_{Mk} as shown in Fig.2, the node corresponding to the selected concentration will be the next growing point. Repeat the above process until there is no new branch to grow and hence a complete plant will be formed.

Chung Wang *et al.* [24] suggested a model where the nodes on a plant can express the possible solutions, f(N) 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 basic point of the next searching process. In this way, the growth process of plant phototropism can be applied to solve the problem of integer programming.

V. APPLICATION OF PROPOSED METHOD

The proposed method has been programmed using MATLAB. The effectiveness of the proposed method for loss reduction by capacitor placement is tested on 34-bus test radial distribution systems [25]. This system has a main feeder and four laterals (sub-feeders). The single line diagram is shown in Fig. 3. The line and load data of the feeders are shown in Table I. The rated line voltage of the system is 11 kV.

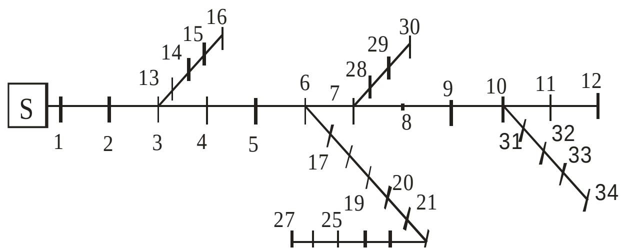

Fig.3 34-Bus Distribution Network

For this test feeder, K_P is selected is selected to be 168\$/(kW-year) [19]. Only fixed capacitors with a life expectancy of 10 years (placement and maintenance costs are neglected) are used in the analysis and the marginal cost of capacitors (K_c^i) [26] given in Table II are used to compute the total annual cost. 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 ($\partial P_{lineloss} / \partial Q_{eff}$) (i.e., bus 19, 22, 20, 21, 23, 24, 25, 26, and 27). Now, the capacitors are placed on these selected buses using PGSA with all possible combinations of buses. Fig. 4 shows the graph between number of buses used for capacitor placement and the corresponding losses in kW. The optimum locations with size of capacitors with the proposed method are compared with the Fuzzy reasoning [27] and are shown in Table III. The minimum voltage before capacitor placement is 0.9417 p.u at bus number 27 which has improved to 0.9493 p.u after capacitors placement

Table III
Simulation Results of 34- Bus System and Its Comparison

Parameters	**Uncompensated**	**Fuzzy Reasoning [27]**		**Proposed PGSA**	
Total losses (kW)	221.67	168.98		168.90	
Loss reduction (%)	…	23.76		23.80	
Optimal location and size in kVAr	…	24 17 7	1500 750 450	19 22 20	900 900 150
Annual Cost (\$ / year)	37,182	29010		28,778	
Net Saving (\$ / year)	…	8,172		8,404	

From the results shown in Table III, it is observed that the power loss obtained with proposed method is less than Fuzzy Reasoning method. Also, the annual cost after the capacitor placement by PGSA method is less than that of Fuzzy Reasoning method.

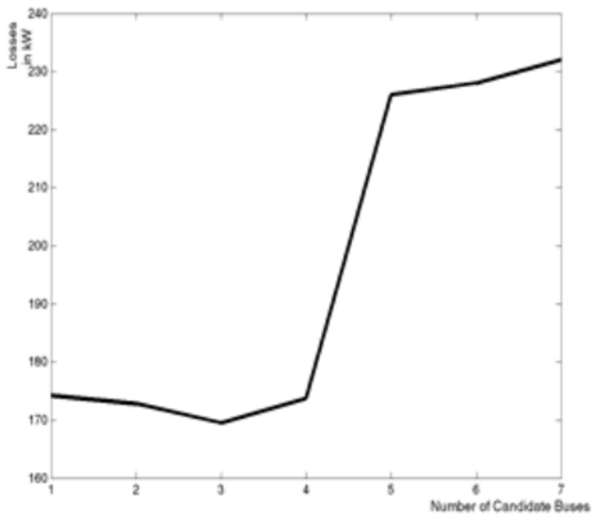

Fig.4 Losses Corresponds to Number of Candidate Buses

VI. CONCLUSION

A bionic random search Plant Growth Simulation Algorithm (PGSA) for loss reduction 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 reduce the active power loss. The test results of 34 bus system have showed the best solutions than other approach available in the reference. PGSA have many characteristics such as fewer parameters, easily coding and implement, fast calculating speed, no more restrictions or requirements in solving the objective function. In this paper, capacitors at less number of locations with optimum size are placed which results in net annual saving. Also, practical values of capacitors are considered with a finite number of sizes rather than continuous capacitors size.

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Table I
Load Data and Feeder Data of 34-Bus System

Bus No.	Load P (kW)	Q (kVAr)	Sectional Parameters				Length km
			Bus No		$R_{i,i+1}$	$X_{i,i+1}$	
			From	To	(ohm/km)	(ohm/km)	
1	230	142.5	0	1	0.195	0.08	0.6
2	0	0	1	2	0.195	0.08	0.55
3	230	142.5	2	3	0.299	0.083	0.55
4	230	142.5	3	4	0.299	0.083	0.5
5	0	0	4	5	0.299	0.083	0.5
6	0	0	5	6	0.524	0.09	0.6
7	230	142.5	6	7	0.524	0.09	0.4
8	230	142.5	7	8	0.524	0.09	0.6
9	0	0	8	9	0.524	0.09	0.4
10	230	142.5	9	10	0.524	0.09	0.25
11	137	84	10	11	0.524	0.09	0.2
12	72	45	2	12	0.524	0.09	0.3
13	72	45	12	13	0.524	0.09	0.4
14	72	45	13	14	0.524	0.09	0.2
15	13.5	7.5	14	15	0.524	0.09	0.1
16	230	142.5	5	16	0.299	0.083	0.6
17	230	142.5	16	17	0.299	0.083	0.55
18	230	142.5	17	18	0.378	0.086	0.55
19	230	142.5	18	19	0.378	0.086	0.5
20	230	142.5	19	20	0.378	0.086	0.5
21	230	142.5	20	21	0.524	0.09	0.5
22	230	142.5	21	22	0.524	0.09	0.5
23	230	142.5	22	23	0.524	0.09	0.6
24	230	142.5	23	24	0.524	0.09	0.4
25	230	142.5	24	25	0.524	0.09	0.25
26	137	85	25	26	0.524	0.09	0.2
27	75	48	6	27	0.524	0.09	0.3
28	75	48	27	28	0.524	0.09	0.3
29	75	48	28	29	0.524	0.09	0.3
30	57	34.5	9	30	0.524	0.09	0.3
31	57	34.5	30	31	0.524	0.09	0.4
32	57	34.5	31	32	0.524	0.09	0.3
33	57	34.5	32	33	0.524	0.09	0.2

Table II

Possible Size of Capacitors in $/kVAr

Q_j^c	150	300	450	600	750	900	1050
$/kVAr	0.500	0.350	0.253	0.220	0.276	0.183	0.228
J	8	9	10	11	12	13	14
Q_j^c	1200	1350	1500	1650	1800	1950	2100
$/kVAr	0.170	0.207	0.201	0.193	0.187	0.211	0.176
J	15	16	17	18	19		
Q_j^c	2250	2400	2550	2700	2850		