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Minimization of Power Losses in Distribution System using Modified Plant Growth Simulation Algorithm (MPGSA)

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***Abstract*- Distribution system is the bridge between the high voltage transmission system and the consumer. The important requirement of a distribution system is that it should have less losses and better voltage profile. A substantial amount of power is lost in the distribution system in the form of losses. Technical losses are mainly the power dissipation in the electrical system. Losses can be reduced by placing the optimal sized capacitors at optimum locations of the buses. The objective is to achieve the optimal value satisfying the system constraints. This also improves the voltage profile of the test systems. The solution methodology has been discussed into two parts. In first part, the candidate buses for the compensation shall be selected using loss sensitivity factors and in the second part, sizing of the capacitors shall be done by applying modified plant growth simulation algorithm (MPGSA). MPGSA is based on growth laws of plant by which a probability model of plant growth can be designed. MPGSA is modified version of Plant Growth Simulation Algorithm (PGSA). Earlier PGSA had only one new basic point but in this proposed work, MPGSA generates many new basic points in each generation which results into improved optimizing efficiency. The proposed method is applied to IEEE 15 and 34 bus radial distribution systems. This method gives better results as compared to other methods.**

***Index Terms*- Reactive Power Compensation, MPGSA, Capacitor Placement, Loss Sensitivity Factor, Distribution System, Loss Reduction.**

I. INTRODUCTION

Conservation of power has become a prime focus in the present time of energy crisis. A lot of amount of total power production is wasted in the form of losses at the time of distribution of electricity. Loss minimization is more feasible and cheaper than an increasing generation level [1]. at the consumer's end. Fluctuations in voltage may lead to loss of revenue in terms of power loss and cause permanent equipment failure. A distribution system should therefore ensure that voltage fluctuations at the end of the consumer must be within allowable limits. The stable voltage limit at user's end is +/-5 percent of the rated voltage [2]. The primary cause of the voltage drop into the line is the reactive power transfer by the line [3]. Many methods have been suggested by the researchers in the past for loss minimization and voltage profile enhancement [4-16]. In this work, loss minimization and voltage profile enhancement is done by compensating the reactive power with the help of placing optimal size of capacitor at suitable bus locations. The proposed work has been done in two phases; one is to find the suitable locations for capacitor placement using loss sensitive analysis and another is to find the optimal capacitor size using Modified plant growth simulation (MPGSA).

II. PROBLEM FORMULATION

Losses can be reduced by using optimal sizing of capacitors at optimum bus locations. There can be many capacitors combinations that can reduce losses. But the best solution is the selection of capacitors for which the cost of losses and costs of capacitors is minimal. Hence, the objective function can be considered as a cost function namely TAC (Total Annual Cost) to minimize the losses.

Objective Function

Minf= Minimize (TAC)

The TAC function comprises of following terms:

(i) Cost equivalent to reduction of power loss in the system.

(ii) Capacitors placement cost.

(iii) Installation cost of capacitors.

This cost can be defined as follows:

$$TAC = K_p P_{T,}Loss + \sum_{i=1}^{n} K_i^{c} Q_i^{C} + K_f \quad (2.1)$$

Where,

P_TLoss is the system's total power loss, which is the sum of losses from all the line sections of different feeders

$K_p$is the annual cost per unit of power loss in $/ (Kw-year).

$K_i^{c}$is the annual cost of capacitor placement in $/kVAr,

i= 1, 2,3,.... ,n are the indices of the candidate buses selected for compensation

Q_i^{C} is the size of capacitor in kVAr connected to i^{th}bus.

K_f is installation cost of capacitor.

Constraints

The objective function is subjected to following constraints:

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

Where,

V_i is the voltage magnitude of i^{th} bus

$V_{min,i} V_{max,i}$ are the minimum and maximum voltage limits of i^{th} bus. The voltage magnitude at each bus must be maintained within these limits.

(ii) Bus reactive compensation power

$$Q_i^{C} \leq \sum_{i=1}^{n} Q_{Li}$$

Where,

Q_i^{C} is the reactive power compensated at bus i^{th}

Q_{Li} is the reactive load power at i^{th} bus.

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This constraint will avoid any overcompensation in the system.

III. SENSITIVITY ANALYSIS

The main objective of the analysis of sensitivity is to determine the rate of change in a system's output variables as a result of changes in a set of system parameters. A sensitivity analysis is used to decide locations of suitable buses to place capacitors to minimize technical losses which will help to reduce the search space for optimization.

Consider the impedance R+jX of a distribution line and a load of Peff + jQeff connected to the buses ' p' and' q' as shown below Fig.3.1

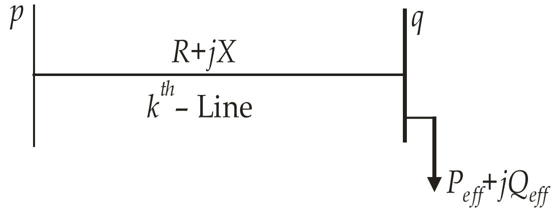

Fig.3.1. P and Q Buses with Distribution Line

Loss of active power in the Kth line $\left[I_k^2\right] * R[k]$ can be expressed as,

$$P_{lineloss}[q] = \frac{(P_{eff}^2[q] + Q_{eff}^2[q] R[k])}{(V[q]) * (V[q])} \quad (3.1)$$

The reactive power in the Kth line is also given by

$$Q_{lineloss}[q] = \frac{(P_{eff}^2[q] + Q_{eff}^2[q] X[k])}{(V[q]) * (V[q])} \quad (3.2)$$

Where, Peff[q] is all active power provided excess of node ‘q’ and Qeff[q] is total effective reactive power in excess of the node ‘q’.

The Loss Sensitivity Factors can now be express [17]:

$$\frac{\partial P_{lineloss}}{\partial Q_{eff}} = \frac{(2 * Q_{eff}[q] * R[k])}{(V[q]) * (V[q])} \quad (3.3)$$

$$\frac{\partial Q_{lineloss}}{\partial Q_{eff}} = \frac{(2 * Q_{eff}[q] * X[k])}{(V[q]) * (V[q])} \quad (3.4)$$

Loss sensitivity factors ($\partial P_{lineloss} / \partial Q_{eff}$) are determined from analysis of load flow the sequence in which the buses are to be considered for compensation shall be determined by the descending order of these LSF. The buses in which normalized voltage magnitude is less than 1.01 are regarded as suitable selected buses at which capacitor must be placed. LSF therefore determine the order in which buses are to be considered for compensation and the normalized voltage determines whether or not the buses need to compensate for reactive power.

IV. MODIFIED PLANT GROWTH SIMULATION ALGORITHM (MPGSA)

If MPGSA algorithm gives an artificial environment similar to the environment delivered for plant growth by phototropism. Depending on the changes in the objective function, MPGSA determines the probability of various growth points. The plant phototropism mechanism is stimulated by the instant of the growth hormone known as auxin and establishes a dynamic mechanism in which the branches and leaves grow in the light due to their different intensities in the attraction area. This leads to an optimal global solution. MPGSA is modified version of PGSA as discussed in [5, 18]. Similar to PGSA, MPGSA also follows the growth laws of plant on the basis of which a probability model of plant growth can be formulated. The modification proposed in this dissertation is related to the searching of new basic points. In basic PGSA, only one new basic point is selected out of growth Points. But MPGSA generates many new basic points in each generation to form a group of new basic points. MPGSA results in improved optimizing efficiency by expanding the searching range and hence, the proposed modification gives the revaluating and reselecting chances to the growth points in all generations which can avoid falling into local optimum. The probability model of MPGSA is discussed below:

A plant grows from its root a trunk M. If k nodes named as BM1, BM2, BM3…..BMkhave a superior environment than root B0 on the trunk M, i.e. function g(Y) of the nodes BM1, BM2, BM3…..BMk and B0 satisfy g(BMi)<g(Bo) (i=1,2,3….k) then the concentration of auxins CM1,CM2…………..CMk of the nodes BM1, BM2…..BMk can be calculated by

$$C_{Mi} = \frac{g(B_0) - g(B_{Mi})}{\Delta_1} \quad (4.1)$$

$$\Delta_1 = \sum_{i=1}^{k} \left[g(B_0) - g(B_{Mi}) \right]$$

Where, (4.2)

The meaning of the equation (4.1) is that the node's concentration of auxins does not based on its environmental information. But it also based on other nodes in the plant's environmental information. This expresses the relationship into the concentration of auxins and the environment. We can derive $\sum_{i=1}^{k} C_{Mi} = 1$, from (4.1), which means that the concentrations of auxins CM1,CM2…………..CMk of the nodes BM1, BM2…..BMk form a state space shown in Figure 4.1.

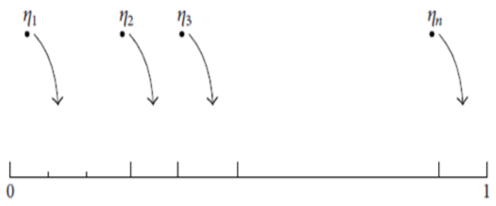

Fig.4.1. Auxin Concentration State Space

The selection of a random numbers in the interval [0,1] falls into one of CM1,CM2…………..CMk in fig.4.1, the similar node known as the preferential growth node will be given priority in the next step to grow a new branch.

Hence, equation (4.1) can be modified as

$$0 \leq \beta \sum_{j=1}^{n} \beta \leq \sum_{i=1}^{T} C_{Mi} \quad (T = 1) \quad (4.3)$$

Or

$$\sum_{i=1}^{T} C_{Mi} < \sum_{j=1}^{n} \beta \leq \sum_{i=1}^{T} C_{Mi}$$

$$(T = 2,3\ldots.k) \quad (4.4)$$

Supposing there are q nodes Bm1,Bm2….Bmq, on the branch m, which have a better environment than the root B0, and their corresponding concentrations of auxins are

Cm1,Cm2….Cmq. Now, it is necessary to calculate not only the auxin concentrations of the nodes on the branch m, but also the auxin concentrations of the nodes on the trunk except for BM2 (the auxin concentration of the node BM2 is zero after the growth of the branch m). The calculation can be carried out using (4.6), which is obtained from (4.1), by adding the related terms of the branch nodes and abandoning the related terms of the Bm2 node.

$$C_{MI} = \frac{g(B_0) - g(B_{Mi})}{\Delta_1 + \Delta_2} \quad (i = 1,3,....k\ )$$

and

$$C_{mj} = \frac{g(B_0) - g(B_{mj})}{\Delta_1 + \Delta_2} \quad (j = 1,2,....q) \quad (4.6)$$

where,

$$\Delta_1 = \sum_{i=1, i\neq 2}^{k} \left[g(B_0) - g(B_{Mi}) \right] \quad (4.7)$$

$$\Delta_2 = \sum_{j=1}^{q} \left[g(B_0) - g(B_{mj}) \right]$$

and (4.8)

A new state space is now formed by the auxin concentrations of the nodes on trunk M and branch m. Hence, a new preferential growth node can be gained, on which a new branch will grow in the next step. This process is repeated until a new branch is developed and a plant is formed.

Steps involved in Modified Plant Growth Simulation Algorithm (MPGSA) for optimal capacitor placement sizing is as follows:

1. Input the system data such as line and load details of the distribution system, constraints limits etc.
2. Set the range of capacitor ratings (kVAr ratings) available which corresponds to the length of the trunk and the branch of a plant.
3. Give the initial solution which corresponds to the root of a plant and calculate the initial value of objective function.
4. Let the initial value of solution is f(Xo).Now, let the objective function value of the solution is equal to Fbest.
5. Identify the candidate buses for capacitor placement using Loss Sensitivity Factors.
6. Initialize iteration count, i=1.
7. Select new basic points Xbasicpoints correspond to the initial kVAr. Place this kVAr at sensitive buses in a sequence starting from basic point to the maximum value.
8. Now, run the load flow to calculate the solutions for corresponding basic points.
9. For each solution in step 8, calculate the total kVAr at the selected buses.
10. If the reactive power limit constraints are satisfied go to step 11; otherwise abandon the possible solution of basic points band go to step 15.
11. For each solution of set of basic points in step 8, calculate the nodes voltages of the buses.
12. If the node voltage constraints are satisfied go to step 13; otherwise abandon the possible solution of basic points and go to step 15.
13. Save the solution as possible feasible solutions iff (Xbasicpoints) is less than f(Xo). The feasible solution will be indicated as X1, X2,..….Xk..
14. Now, calculate the objective function corresponds to the solution of Xbasicpointsas calculated and compare with Fbest. If the solution is less than Fbest, save this solution as Fbest for further iterations ; otherwise go to step 16.
15. If i>=Nmaxgo to step 18; otherwise go to step 16.
16. Calculate the probabilities C1, C2,…Ckof feasible solutions X1,X2,….Xk, by using equation (4.5), which corresponds to determining the auxin concentration of the nodes of a plant.
17. Calculate the accumulating probabilities ΣC1, ΣC2,….ΣCkof the solutions X1 , X2,….Xk. Select random numbers from the interval [0 1] which must belong to one of the intervals [0, ΣC1], (ΣC1, ΣC2], ….,(ΣCk-1, ΣCk]. Hence, new basic points (Xbasicpoints) will be obtainedfor the next iteration which corresponds to the new preferential growth node of a plant for next step.
18. Increment i by i+1 and return to step 7.
19. Output the results and stop.

V. TEST SYSTEM AND SIMULATION RESULTS

5.1 15-Buses Test System

A 15-bus radial distribution system [19] is the first test case for the proposed technique. This system has a main feeder and five side feeders. The initial power loss without capacitor placement was seen to be 61.8 kW. But after optimal capacitor placement using MPGSA the power losses are reduced to 30.5 kW. The uncompensated system's annual power loss cost was $10,381. The total annual cost of power loss and capacitor placement was reduced to $5917.3 after implementation of MPGSA technique. Table 5.1 displays the results of the applied technique. Hence, 50.64 % of loss reduction and 42.998 % of revenue saving have been achieved by the proposed MPGSA technique.

Results obtained by MPGSA are compared with FPA [20] and IHA [21] and are presented in Table 5.1. Table 5.1shows that the results correspond to loss reduction and annual cost saving obtained by MPGSA are better than FPA and IHA methods.

Table 5.1
Test Result-15 Bus System

Parameters	Proposed (MPGSA)		FPA[20]		IHA[21]	
Total losses (kW)	30.5		31.4		31.8	
Loss reduction (%)	50.647		49.190		48.543	
Optimal locations and Size in kVAr	Bus No.	Cap. in kVAr	Bus No.	Cap. in kVAr	Bus No.	Cap. in kVAr
	6	450				
	3	150	6	350	6	350
	11	300	11	350	11	300
	4	300	15	300	15	300
Total kVAr	1200		1000		950	
Annual	5917.3		5969.01		5995.905	

Cost in $			
Net Savings $	4463.7	4411.99	4385.905
% Saving	42.998	42.5	42.241

Before compensation, bus number 13 had the minimum voltage of 0.9445 p.u but this voltage has improved to 0.9694 p.u after applying MPGSA technique before and after compensation. Hence, voltage profile of 15 bus system is enhanced by placing the optimal capacitors at optimum locations using MPGSA which is shown in fig. 5.1.

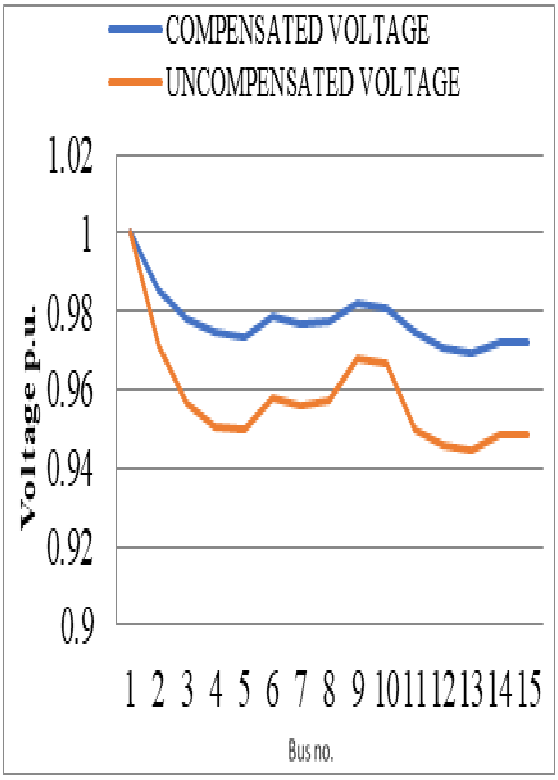

Fig.5.1 Graph between Compensated and Uncompensated Voltage of 15-Bus

Table 5.2 Test Result-34 Bus System

Parameters	Compensated (MPGSA)		PGSA[23]		PSO[24]	
Losses (Kw)	166.8		169.1		167	
Reduction on Losses (%)	24.76		23.72		24.67	
Optimal Bus No. and size in kVAr	Bus No.	Cap. in kVAr	Bus No.	Cap. in kVAr	Bus No.	Cap. in kVAr
	19	1200	19	1200	19	1050
	22	450	22	639	22	300
	26	450	20	200	26	600
Total KVAR	2100		2039		1950	
Annual Cost ($/Year)	28748		29169		28826.4	
Annual Saving($/Year)	8493		8072		8414.6	
Saving (%)	22.8		21.67		22.59	

5.2 34-Bus Test System

A 34-bus radial distribution system [22] is the first test case for the proposed technique. This system has a main feeder and five side feeders. The initial power loss without capacitor placement was seen to be 221.67 kW. But after optimal capacitor placement using MPGSA the power losses are reduced to 166.8 kW. The uncompensated system's annual power loss cost was $37,182. The total annual cost of power loss and capacitor placement was reduced to $28748 after implementation of MPGSA technique. Table 5.2 displays the results of the applied technique. Hence, 24.76% of loss reduction and 22.8% of revenue saving have been achieved by the proposed MPGSA technique.

Results obtained by MPGSA are compared with PSO [23] and PGSA [24] and are presented in Table 5.2 Table 5.2 shows that the results correspond to loss reduction and annual cost saving obtained by MPGSA are better than PSO and PGSA methods.

Before compensation, bus number 27 had the minimum voltage of 0.9417 p.u but this voltage has improved to 0.9503 p.u after applying MPGSA technique of different buses voltages before and after compensation. Hence, voltage profile of 34 bus system is enhanced by placing the optimal capacitors at optimum locations using MPGSA which is shown in fig. 5.2

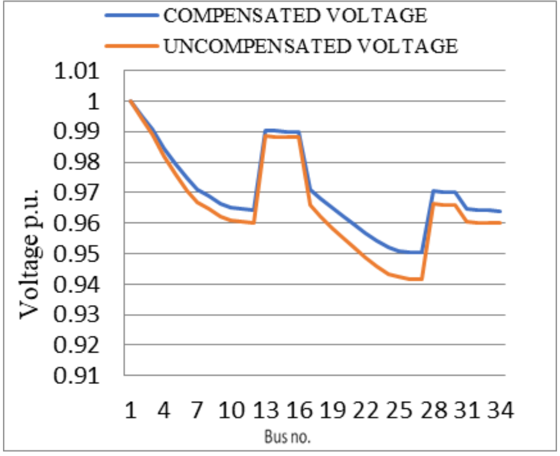

Fig.5.2. Graph between Compensated and Uncompensated Voltage of 34-Bus

VI. CONCLUSION

The effectiveness of the proposed method for loss reduction by capacitor placement has been tested on 15 bus and 34-bus test radial distribution systems and results have also been compared with other approaches. We have further found that results obtained by MPGSA are better than other approaches.

The first test case for the proposed method is a 15 bus radial distribution system. The rated line voltage of the system is 11 kV and total reactive load is 1251 kVAr. Buses 6, 3, 11 and 4 can be selected as the candidate buses for the capacitor placement using loss sensitivity analysis. On applying Newton Raphson Load flow method, the initial power loss was 61.8 kW and after capacitor placement using the proposed method it is reduced to 30.5 kW. Annual cost for uncompensated system was $ 10,381 and after applying MPGSA method the cost has been reduced to $ 5917.3 and hence 42.998% saving has been achieved. By placing the optimal capacity of capacitors at optimal locations, the voltages at buses have also improved. Bus number 13 has lowest voltage of 0.944517 p.u. which has been improved to 0.9694 p.u.

The second test case for the proposed method is a 34 bus radial distribution system The rated line voltage of the system is 11 kV and total reactive load is 2873 kVAr. Buses 19, 22, 26 have been selected as the candidate buses for the capacitor placement using loss sensitivity analysis. Initial power loss is 221.67 kW and after capacitor placement using the proposed method it is reduced to 166.8 kW. Total annual cost for uncompensated system was $ 37,182 and after applying MPGSA method the cost has been reduced to $ 28748 and hence 22.8% saving has been achieved. By placing the optimal capacity of capacitors at optimal locations, the voltages at buses have also improved. Bus number 27 has lowest voltage of 0.9417 p.u. which has been improved to 0.9503 p.u.

Appendix

PGSA-Plant Growth Simulation Algorithm, MPGSA-Modified Plant Growth Simulation, Algorithm, MATLAB-Matrix Laboratory, PSO-Particle Swarm Optimization, FPA- Flower Pollination Algorithm, PLI- Power Loss Index, LSF-Loss Sensitivity Factor, IHA-Improved Harmony Algorithm, KVAR-Kilo-Volt Ampere Reactive, NR-Newton Raphson.

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