Power Loss Reduction in Radial Distribution System by Using Plant Growth Simulation Algorithm

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Abstract

The availability of an adequate amount of electricity and its utilization is essential for the growth and development of the country. The demand for electrical energy has outstripped the availability causing widespread shortages in different areas. The distribution network is a crucial network, which delivers electrical energy directly to the doorsteps of the consumer. In India the distribution networks are contributing to a loss of 15% against total system loss of 21%. Hence, optimal capacitor placement in electrical distribution networks has always been the concern of electric power utilities. As Distribution Systems are growing large and being stretched too far, leading to higher system losses and poor voltage regulation, the need for an efficient and effective distribution system has therefore become more urgent and important. In this regard, Capacitor banks are added on Radial Distribution system for Power Factor Correction, Loss Reduction and Voltage profile improvement. Reactive power compensation plays an important role in the planning of an electrical system. Capacitor placement & sizing are done by Loss Sensitivity Factors and Plant Growth Simulation Algorithm respectively. Loss Sensitivity Factors offer the important information about the sequence of potential nodes for capacitor placement. These factors are determined using single base case load flow study. Plant Growth Simulation Algorithm is well applied and found to be very effective in Radial Distribution Systems. The proposed method is tested on 33 and 34 bus distribution systems. The objective of reducing the losses and improvement in voltage profile has been successfully achieved. The main advantage of the proposed approach in relation to previously published random algorithms is that it does not require any external parameters such as barrier factors, crossover rate, mutation rate, etc. These parameters are hard to be effectively determined in advance and affect the searching performance of the algorithm.

Keywords: Distribution systems, Loss Sensitivity Factors, Capacitor placement, Plant growth simulation algorithm.

1. Introduction

Distribution systems are the networks that transport the electric energy from bulk substation to many services or loads, thus causes more power and energy losses. Hence there is a need to reduce the system losses. By minimizing the power losses, the system may acquire longer life span and has greater reliability.

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. Studies have indicated that as much as 13% of total power generated is consumed I^2R as losses at the distribution level. Reactive currents account for a portion of these losses. However, the losses produced by reactive currents can be reduced by the installation of shunt capacitors. Effective capacitor installation can also release additional KVA capacity from distribution apparatus and improve the system voltage profile. Reactive power compensation plays an important role in the planning of an electrical system. As Distribution Systems are growing large and being stretched too far, leading to higher system losses and poor voltage regulation, the need for an efficient and effective distribution system has therefore become more urgent and important. In this regard, Capacitor banks are added on Radial Distribution system for Power Factor Correction, Loss Reduction and Voltage profile improvement. Therefore it is important to find optimal location and sizes of capacitors required to minimize feeder losses.

2. Problem Formulation:

The capacitor placement problem is the determination of the location, number, type and sizes of capacitors to be placed on a radial distribution system in an optimal manner. The objective is to reduce the energy losses and peak power losses on the system while striving to minimize the cost of capacitors in the system. The optimum location for the capacitors is determined such that it minimizes the power losses and reduces the overall cost of the distribution system under study. The capacitor-allocation problem has been solved by Plant Growth Simulation algorithm and tests are done on standard 33 bus and 34-bus system. The problem is formulated as a constrained optimization problem. In this constrained problem the constraint is the voltage limit i.e. if the voltage magnitude exceeds specified limit it increases the power loss function. Since the addition of capacitor at any bus in the distribution system results in voltage magnitude increase, therefore it becomes imperative to model voltage magnitude as a constraint in the mathematical equation which is to be optimized. Here line flow limits are taken care by the dedicated distribution load flow program that calculates the losses.

The cost function (Savings function), that is minimized as a consequence of power loss reduction, is formulated as:

$$Cost = K_p \Delta P_{loss} T - \sum_{i=1}^{n} K_c C_i$$

Where

Kp is cost per Kilowatt-hour (Rs/kWh)

ΔP is the total power loss reduction in the system in KW

Kc cost per Kvar (Rs/Kvar)

Ci is the value of shunt capacitor at the ith bus in Kvar

T is the time in Hrs

The first term in cost function indicates savings due to power loss reduction i.e. Rs/Hr saved and second term stands for total capacitor cost. Optimum capacitor allocation reduces the losses but at the same time capacitor cost increases drastically as the number of capacitors are increased. But since it is assumed that capacitor cost is one time investment the payback period can be easily calculated.

3. Sensitivity Analysis and Loss Sensitivity Factors :

A Sensitivity Analysis is used to determine the candidate nodes for the placement of capacitors using Loss Sensitivity Factors. The estimation of these candidate nodes basically helps in reduction of the search space for the optimization procedure. The sensitivity analysis is a systematic procedure to select those locations which have maximum impact on the system real power losses, with respect to the nodal reactive power. Loss Sensitivity Factors can be obtained as

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

Where

Qeff [q] = Total effective reactive power supplied beyond the node 'q'.

Plineloss=Active Power loss of the kth line.

R[k] =Resistance of the kth line.

V[q] =Voltage at node'q'.

∂Ploss/∂Q = Loss Sensitivity Factor.

Sensitivity factors decide the sequence in which buses are to be considered for compensation placement. The node with the highest sensitivity factor is the first to be compensated with capacitor.

3. Solution Methodologies:

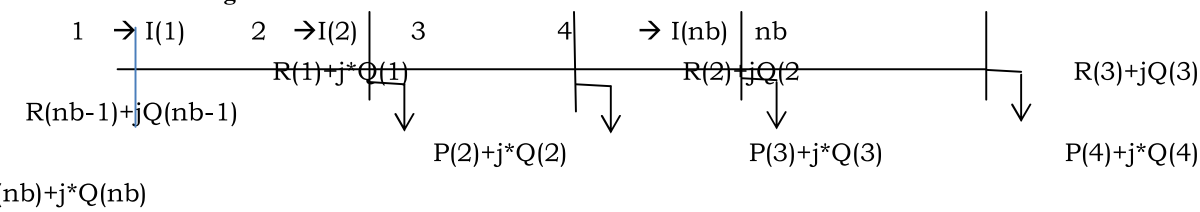

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Fig 1. Radial main feeder

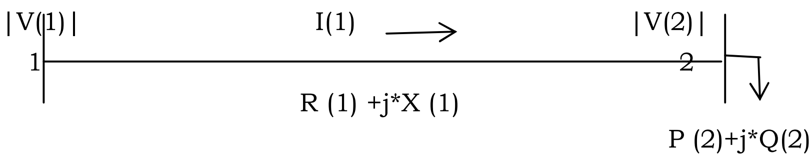

Fig 2.Electrical equivalent of fig 2

Consider a distribution system consisting of a radial main feeder only. The one line diagram of such a feeder comprising n nodes and n-1 branches is shown in Fig. 2. From Fig.2 and 3, the following equations can be written

$$I(1) = \frac{|V(1)|\llcorner\delta(1) - |V(2)|\llcorner\delta(2)}{(R(1)+j*X(1))} \qquad \text{(1)}$$

$$P(2)-j*Q(2)=V^*(2)I(1) \qquad (2)$$

From eqns. 1 and 2 we have

$$|V(2)|=[\{P(2)R(1)+Q(2)X(1)-0.5|V(1)|^2)^2-(R^2(1)+X^2(1))(P^2(2)+Q^2(2))\}^{1/2} -(P(2)R(1)+Q(2)X(1)-0.5|V(1)|^2)]^{1/2} \qquad (3)$$

Eqn. 3 can be written in generalized form

$$|V(i+1)|=[\{P(i+1)R(i)+Q(i+1)X(i)-0.5|V(i)|^2)^2-(R^2(i)+X^2(i))(P^2(i+1)+Q^2(i+1))\}^{1/2} -(P(i+1)R(i)+Q(i+1)X(i)-0.5|V(i)|^2)]^{1/2} \qquad (4)$$

Eqn. 4 is a recursive relation of voltage magnitude. Since the substation voltage magnitude |V(1)| is known, it is possible to find out voltage magnitude of all other nodes. From Fig. 2.2 the total real and reactive power load fed through node 2 are given by

$$P(2)=\sum_{i=2}^{nb} PL(i)+\sum_{i=2}^{nb-1} LP(i) \qquad (5)$$

$$Q(2)=\sum_{i=2}^{nb} QL(i)+\sum_{i=2}^{nb-1} LQ(i)$$

It is clear that total load fed through node 2 itself plus the load of all other nodes plus the losses of all branches except branch 1.

$$LP(1)=(R(1)*[P^2(2)+Q^2(2)])/(|V(2)|^2) \qquad (6)$$

$$LQ(1)=(X(1)*[P^2(2)+Q^2(2)])/(|V(2)|^2)$$

Eqn. 5 can be written in generalized form

$$P(i+1)=\sum_{i=2}^{nb} PL(i)+\sum_{i=2}^{nb-1} LP(i) \quad \text{for } i=1, 2\ldots nb-1 \qquad (7)$$

$$Q(i+1)=\sum_{i=2}^{nb} QL(i)+\sum_{i=2}^{nb-1} LQ(i) \quad \text{for } i=1, 2\ldots nb-1$$

Eqn. 6 can also be written in generalized form

$$LP(i)=(R(i)*[P^2(i+1)+Q^2(i+1)])/(|V(i+1)|^2) \qquad (8)$$

$$LQ(1)=(X(i)*[P^2(i+1)+Q^2(i+1)])/(|V(i+1)|^2)$$

Initially, if LP (i+1) and LQ (i+1) are set to zero for all I, then the initial estimates of P (i+1) and Q (i+1) will be

$$P(i+1)=\sum_{i=2}^{nb} PL(i) \quad \text{for } i=1, 2\ldots NB-1 \qquad (9)$$

$$Q(i+1)=\sum_{i=2}^{nb} QL(i) \quad \text{for } i=1, 2\ldots NB-1$$

Eqn. 9 is a very good initial estimate for obtaining the load flow solution of the proposed method.

The convergence criteria of this method is that if the difference of real and reactive power losses in successive iterations in each branch is less than 1 watt and 1 var, respectively, the solution has converged

4. Plant Growth Simulation Algorithm:

The plant growth simulation algorithm characterizes the growth mechanism of plant phototropism, is a bionic random algorithm. It looks at the feasible region of integer programming as the growth environment of a plant and determines the probabilities to grow a new branch on different nodes of a plant according to the change of the objective function, and then makes the model, which simulates the growth process the growth process of a plant, rapidly grow towards the light source i.e; global optimum solution.

(i)Growth Laws of a Plant:

a) In the growth process of a plant, the higher the morphactin concentration of a node, the greater the probability to grow a new branch on the node.

b) The morphactin concentration of any node on a plant is not given beforehand and is not fixed. It is determined by the environmental information of a node depends on its relative position on the plant. The morphactin concentrations of all nodes of a plant are allowed again according to the new environment information after it grows a new branch.

(ii)Probability Model of Plant Growth:

Probability model is established by simulating the growth process of a plant phototropism. 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 the environment of the node **Y** for growing a new branch. The main outline of the model is as follows: A plant grows a trunk M, from its root B_o . Assuming there are k nodes $B_{M1,}$ B_{M2} ,B_{M3},….B_{MK} that have better environment than the root B_O on the trunk M , which means the function g(Y) of the nodes and satisfy $g(B_{Mi}) < g(B_o)$ then morphactin concentrations C_{M1},C_{M2},….C_{Mk} of nodes $\mathbf{B_{M1,}}$ $\mathbf{B_{M2}}$,$\mathbf{B_{M3}}$,….$\mathbf{B_{MK}}$ are calculated using

$$C_{Mi}= (g(B_o)- g(B_{Mi}))/\Delta_1 \ (i=1,2,3,\ldots k) \qquad (4.1)$$

Where $\Delta_1=\sum_{i=1}^{n}(g(Bo) - g(BMi))$

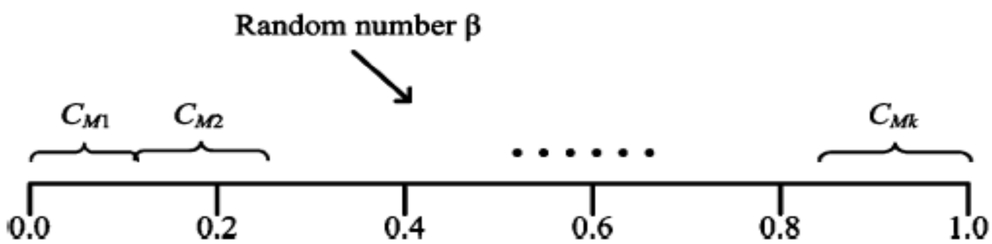

Fig 4.1: morphactin concentration state space

The significance of (1) is that the morphactin concentration of a node is not 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 (1), we can derivate $\sum C_{Mi}=1$, of the nodes form a state space shown in Fig. 4.1. Selecting a random number β in the interval [0, 1] and will drop into one of C_{M1}, C_{M2}, ….C_{Mk} in Fig. 2, then the corresponding node that is 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 $0 \le \beta \le \sum_{i=1}^{T} C_{Mi}$. (T=1) or $\sum_{i=1}^{T-1} C_{Mi} \le \beta \le \sum_{i=1}^{T} C_{Mi}$ (T=2, 3,4,5…k) .For example, if random number β drops into C_{M2} , which means $\sum_{i=1}^{1} C_{Mi} \le \beta \le \sum_{i=1}^{2} C_{Mi}$ then the node B_{M2} will grow a new branch m . Assuming there are q nodes, which have better environment than the root $\mathbf{B_O}$, on the branch m, and their corresponding morphactin concentrations are C_{m1}, Cm2,.C_{mq}. Now, not only the morphactin concentrations of the nodes on branch m, need to be calculated, but also the morphactin concentrations of the nodes except B_{M2} (the morphactin concentration of the node becomes zero after it growing the branch) on trunk need to be recalculated after growing the branch . The calculation can be done using (4.2), which is gained from (4.1) by adding the related terms of the nodes on branch m and abandoning the related terms of the node $\mathbf{B_{M2}}$

$$C_{Mi}= (g(B_o)- g(B_{Mi}))/(\Delta_1+ \Delta_2) \qquad (i=1,2,3,\ldots k)$$
$$C_{Mj}= (g(B_o)- g(B_{Mj}))/(\Delta_1+ \Delta_2) \qquad (j=1,2,3\ldots.q) \qquad (4.2)$$
Where $\Delta 1=\sum_{i=1}^{k}(g(Bo) - g(B_{Mi}))$
Where $\Delta 2=\sum_{j=1}^{q}(g(Bo) - g(B_{Mj}))$
We can also derivate $\sum_{i=1}^{k} C_{Mi}(i \neq 2)+ \sum_{j=1}^{q} C_{Mj} =1$ from(10). Now, the morphactin concentrations of the nodes (except $\mathbf{B_{M2}}$) on trunk M and branch m will form a new state space

(The shape is the same as Fig. 2, only the nodes are more than that in Fig. 2). A new preferential growth node, on which a new branch will grow in the next step, can be gained in a similar way

as $\mathbf{B_{M2}}$.

Such process is repeated until there is no new branch to grow, and then a plant is formed.

From the viewpoint of optimal mathematics, 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 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.

4.2 ALGORITHM FOR CAPACITOR PLACEMENT:

1. Read System Data

2. Let assume some range of capacitor ratings i.e.,kvar, take it as initial solution xo, which corresponds to the root of the plant

3. Run load flow for radial distribution system and calculate the initial objective function(power loss) f(X_o)

4. Identify the candidate buses for placement of capacitors using Loss Sensitivity Factors.

5. Let X^b be initial preferential growth node of a plant, and the initial value of optimization X^{best} equal to X_o.

6. Let iteration count N=1;

7. Search for new feasible solutions: place kvar at sensitive nodes in a sequence starting from basic point $X^b=[X_1^b,X_2^b,\ldots.X_i^b,\ldots\ldots..X_n^b]$.

$X^{b\text{ corresponds}}$ to the initial kvar.

8.For the found every possible solution X^p, carry out the check of node voltage constraints and branch power. Abandon the possible solution X^p if it does not satisfy the constraints, otherwise calculate powerloss i.e; objetive function $f(X^p)$ and compare with $f(X_o)$. Save the feasible solutions if $f(X^p)$ less than $f(X_o)$;if no single feasible solution does not satisfy $f(X^p) < f(X_o)$ go to step11

9.Calculate the probabilities $C_1, C_2, \ldots C_k$ of feasible solutions $X_1, X_2, \ldots X_k$, by using

$$C_{Mi} = \frac{g(B_O)-g(B_{Mi})}{\Delta_1} \qquad (i=1, 2\ldots\ldots, k)$$

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

which corresponds to determining the morphactin concentration of the nodes of a plant.

10.Calculate the accumulating probabilities $\sum C_1, \sum C_2, \ldots \sum C_k$ of the solutions $X_1, X_2, \ldots X_k$. select a random number βfrom the interval [0 1], β must belong to one of the intervals $[0\ \sum C_1]$, $(\sum C_1, \sum C_2]$, …,$(\sum C_{k-1}, \sum C_k]$, the accumulating probability of which is equal to the upper limit of the corresponding interval,will be the new basic point for the next iteration ,which corresponds to the new preferential growth node of a plant for next step, and go to step6. N>Nmax is the stopping criteria, where Nmax is a given allowable consecutive iteration number, the choice of Nmax depends on the size and difficulty of the problem. If stopping criteria is satisfied go to next step, otherwise increase iteration count N and go to step6.

11.Save the new feasible solution, which corresponds final solution

5. Conclusion

A Plant Growth Simulation Algorithm is a new and efficient method for the optimization of power distribution systems, where the objective is to minimize the total real power loss. The simulation results based on a 33-bus system and a 34-bus system have produced the best solutions that have been found using a number of approaches available in the technical literature.

The advantages of PGSA over other approaches are:

1) The proposed approach handles the objective function and the constraints separately, avoiding the trouble to determine the barrier factors.

2) It does not require any external parameters such as crossover rate and mutation rate in genetic algorithm;

3) The proposed approach has a guiding search direction that continuously changes as the change of the objective function. This method is not only helpful for operating an existing system but also for planning a future system, especially suitable for large-scale practical systems.

Two algorithms are tested for 33 bus and 34 bus systems and observed that PGSA is much faster and accurate compared to genetic algorithm. The PGSA method places capacitors at less number of locations with optimum sizes and offers much saving in initial investment and regular maintenance.

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