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ELECTRICAL DISTRIBUTION SYSTEM PLANNING USING PARTICLE SWARM OPTIMIZATION

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Abstract--- This paper presents distribution system planning using particle swarm optimization technique. First shortest path using 2 different ways is obtained. One is using particle decoding and the other method is obtaining the shortest path from all possible combinations. After getting the shortest path PSO is used for optimizing the current tapping values between maximum and minimum values. Then the reliability of the mesh network has been evaluated by reliability index CLLI. Distribution System planning is an optimization process to obtain a no. of design variables such as : (i) no. of feeders and their routes (ii) no. of sectionalizing switches (iii) radial or mesh network structure. In this work, distribution system planning has been done by using Particle decoding-PSO method and Number Of Combinations-PSO method and the results are compared.

Index Terms--- CLLI, Distribution System, feeder, NDL, PSO, Reliability, and Velocity

1 Introduction

During the last decade, deregulation has resulted in significant restructuring of power systems. This motivates power system planners to design efficient, reliable, and cost effective power networks. Thus there is a great need for efficient distribution system planning algorithm. Distribution system planning is an optimization process to obtain a number of design variables such as: (i) size and location of the substation, (ii) number of feeders and their routes, (iii) number and locations of the sectionalizing switches, and (iv) radial or meshed network structure. The determination of the optimal value of these variables is done by meeting multiple objectives such as: (i) minimization of the installation cost of new facilities (i.e., substations and feeders), (ii) minimization of the operational (maintenance and lost energy) cost, and (iii) maximization of the system reliability.

The reliability of the distribution network is evaluated by a reliability index, i.e., contingency-load-loss index (CLLI)[5], defined as the ratio of the average non-delivered load due to failure of all branches, taken one at a time, to the total load.

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2 Particle Swarm Optimization

Particle Swarm optimization [4] is a global optimization algorithm for dealing with problems in which a best solution can be represented as a point or surface in an n-dimensional space.

2.1 PSO Algorithm

The algorithm of Particle Swarm Optimization is as given below:

Step1: Initialize randomly the individuals of the population. The objective is to be evaluated for each individual.

Step2: Compare each individual's evaluation value with its P_{best}. The best evaluation value among the P_{best} is denoted as G_{best}.

Step3: New velocities are calculated using equation

$$v_{id}^{t+1} = W \times v_{id}^{t} + c_1 \times rand() \times P_{best} \times X_{id}^{t} + c_2 \times rand() \times G_{best} \times X_{id}^{t}$$

Step4: If $v_{id}^{t+1} < v_{d\min}$ *then* $v_{id}^{t+1} = v_{d\min}$

And if $v_{id}^{t+1} > v_{d\max}$ then $v_{id}^{t+1} = v_{d\max}$

Step5: New searching points are calculated using the equation

$$X_{id}^{t+1} = X_{id}^{t} + V_{id}^{t+1}$$

Where i=1,2,.......n

d=1,2...........m

Step6: Check the voltage limits

If $V_{id}^{t+1} < V_{d\min}$ *then* $V_{id}^{t+1} = V_{d\min}$

And if $V_{id}^{t+1} > V_{d\max}$ then $V_{id}^{t+1} = V_{d\max}$

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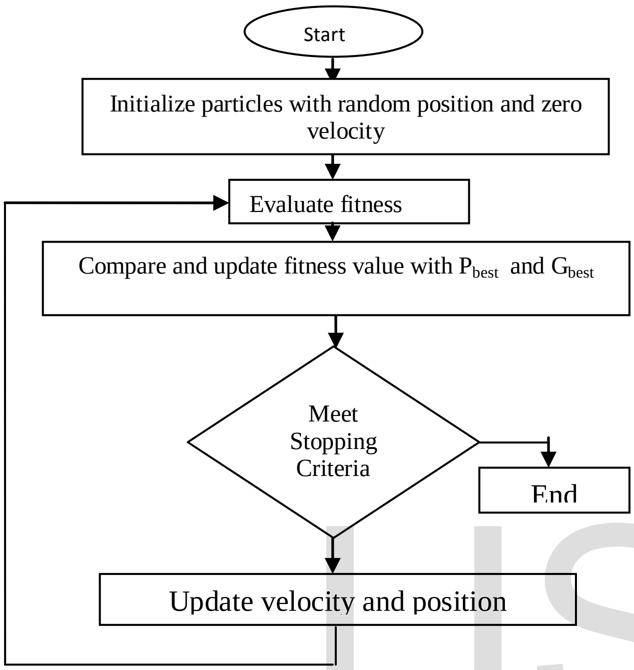
Step7: Evaluate the fitness values for new searching point. If evaluated values of each particle are better than previous I_{best} then set I_{best} to I_{best}. If I_{best} is better than G_{best} then set G_{best} with I_{best}.

2.2 PSO Flow Chart

Fig no: 2 PSO Flow Chart



3 Problem Statement and Objective Function

3.1 Problem Statement

The distribution system is a typical 21-node system. Here, node 1 is a substation and the nodes from 2 to 21 are to be connected to the existing substation. These nodes are connected to the substation by finding optimum routes (radial networks) [2].

- The substation voltage, the minimum and maximum node voltage are taken as 1.05 p.u.,0.92 and 1.08 p.u., respectively.
- The installation cost of conductor for current rating below 150A is $.10000 per Km.
- The installation cost of conductor for current rating above 150A is $.15000 per Km.
- Maintenance cost is 540 $/km/year.

3.2 Objective Function

Objective Function 1:

The objective function is to minimize the feeder installation and maintenance cost. The objective function is as given below:

$$F(c) = \min \sum (CI + CM)$$

Where

CI → Cost of Installation

CM → Cost of Maintenance

Objective Function 2:

The objective function 2 measures network reliability with the CLLI.

$$CLLI = \frac{NDL_{avg}}{L_{total}} = \frac{\left(\sum_{i=1}^{N_b} NDL_i\right)}{N_b L_{total}}$$

Where

NDL_{avg} → Average Non-delivered load due to failure

L_{total} → Total Load

4 Distribution System Planning

The power distribution network is the biggest part of the electrical system, as a result it is chiefly responsible for energy losses. The design of such networks must take into account not only the present load but also the future load i.e., the load that is expected to exist within some time horizon[1]. Consequently electric power distribution network design is a very important skill and use of optimization approaches in the design of this system can lead to important economic earns such as installation cost, maintenance cost, etc.. The planning stage deals with the construction of economic and reliable network. The objective function consists of the minimization of (i) total installation cost & (ii) maintenance cost[7].

A distribution system planning approach is broadly modeled either as a static or a dynamic model. The static planning is based on one-step planning of a new network, whereas a dynamic model is used to plan a network taking load growth at the existing nodes and/or addition of new load nodes. The addition of new nodes to an existing network is generally known as expansion planning. The distribution system planning is aimed at optimizing the total aggregated expenditure of a power utility to serve the customers' load demands which usually grow with time. Thus, this planning is an optimization problem for the determination of optimum values of[3]

- Feeder routing and conductor size for each feeder branch
- Capacity addition of the existing substations
- Conductor replacement of the existing feeder branches.

In this paper feeder routing and conductor size for each feeder branch is considered.

4.1 Finding Shortest Paths for radial networks:

The shortest paths for radial networks of a distribution system can be found in many ways. The two methods used in this work are :

(i) Particle decoding method[1]

(ii) Finding Shortest Path from all possible Combinations

In the later method, find Number Combinations and then calculate lengths of each combination and choose the combination which gives the shortest length.

(i). Finding Shortest Path from Particle decoding method:

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In this decoding scheme, the nodes are selected and appended to the terminal node of a growing path on the basis of minimum value of the product of branch costs and node bias values[6].

j = argmin{$\sigma(i,k)\ \rho k$}, $\sigma(i,k)$ = branch cost (nodes *i*and*k*) .

It is always preferred to connect a node with some neighboring nodes. This feature is incorporated by a binary connectivity matrix M ($n\times n$ matrix for an n-node system). If a connection between nodes *i*and*j* is allowed, $M(i, j) = 1$, else $M(i, j) = 0$. The maximum number of allowable connections for a node is problem specific[8]. The length of a branch is taken as its cost. Initially, the to-be-connected nodes are stored in an array {R} and the substation and the other already connected nodes (if any) are stored in another array {Q}. Two more arrays (initially empty for new network) are used to store the start and end nodes of the branches. The number of nodes directly connected with a substation is restricted to the number of feeders (*NF)* obtained from the particle and they are selected based on minimum distances from the substation. Those nodes are deleted from {R} and added to {Q}; {αs }, {αe} are updated accordingly.

Code for getting radial networks:

Begin

{Q}, ←substation node and nodes to be directly connected to the substation

*(= NF)*based upon distance calculations;

{R}←nodes to be connected with the network;

{αs }, {αe}←start and end nodes of the branches, respectively;

While $(R \neq 0)$

For $i = 1, \ldots, size(Q)$

For $j = 1, \ldots, size(R)$

If $M(Q(i),R(j)) == 1$

$$C(i,j) = \sigma(Q(i), R(j)) \times \rho(j);$$

Endif

Endfor

Endfor

Find the *minimum element of C* and corresponding *Q(i)* and *R(j)*

Update {αs} ← {$\alpha s, Q(i)$}; Update {αe} ← {$\alpha e, R(j)$}

Update {Q} ← {$Q, R(j)$}; Delete {$R(j)$} from R}

Endwhile

End

(ii). Finding Shortest Path from all possible Combinations:

In this method ^nC_r method is used (i.e., number of combinations method) for finding all possible combinations. It is given as :

$$^nC_r = \frac{n!}{r!(n-r)!}$$

Where

r → number of elements to be chosen

n → total number of elements available

In this paper 21 node system is considered. The first node is chosen as substation.

The steps to be followed for finding shortest path are:

Step 1: Find the all possible combinations

Step 2: Find the length of combination by adding the distance between nodes present in that combination.

Step 3: Find the 2 shortest paths in such a way that no single node is repeated in both the networks. (i.e., 2 paths covers all 20 nodes (excluding substation node).

4.2. Finding Current Values at each node:

By following the above steps we will get radial networks After getting these radial networks, using PSO current flowing in feeders has to be optimized, so that, conductors with less cost can be utilized for the feeders. For this, in each iteration we check whether the obtained current (I) is less than the Current value of previous iteration. If it is less than the previous iteration then we replace the current value of that particular node with the present value of current (At the same time we have to check for current limits at each and every node for I_{min} and I_{max}).

The new velocity vector for the new search point is determined by the formula:

$$v_{id}^{t+1} = W \times v_{id}^{t} + c_1 \times rand() \times P_{best} \times X_{id}^{t} + c_2 \times rand() \times G_{best} \times X_{id}^{t}$$

and the new position will b

$$X_{id}^{t+1} = X_{id}^{t} + V_{id}^{t+1}$$

for i=1,2,3,......n

where

n → no. of particles

w → inertia weight

c1,c2 → constant weight factors

P_{best} → best position achieved so long by particle i

G_{best} → best position found by the neighbours of particle i

After getting the values of current at each node find the cost for each route considering total amount of current flowing in each and every feeder. If the current flowing in a particular feeder is less than 150 A then the cost of conductor which has to be used for the feeder is 10000 $/Km. If the amount of current flowing exceeds 150 A in a feeder than the cost of conductor that can with stand this current magnitude is taken as 15000 $/km.

4.3 Formation of loops:

In this step, the radial network is converted into a meshed network. The zones, in which the start and end nodes of a loop-forming branch are located, are obtained from the particle. From these two zones, any two randomly selected nodes are connected to form a loop.

4.4. Sectionalizing switches:

Now, the sectionalizing switches are heuristically placed based on the number of switches obtained from the particle.

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The switch locations are determined as follows:

• The number of switches in an individual feeder (say feeder F_i) is determined as:

$$N_{Sw}^{Fi} = round\left(\frac{n_{Fi}}{n} N_{Sw}\right)$$

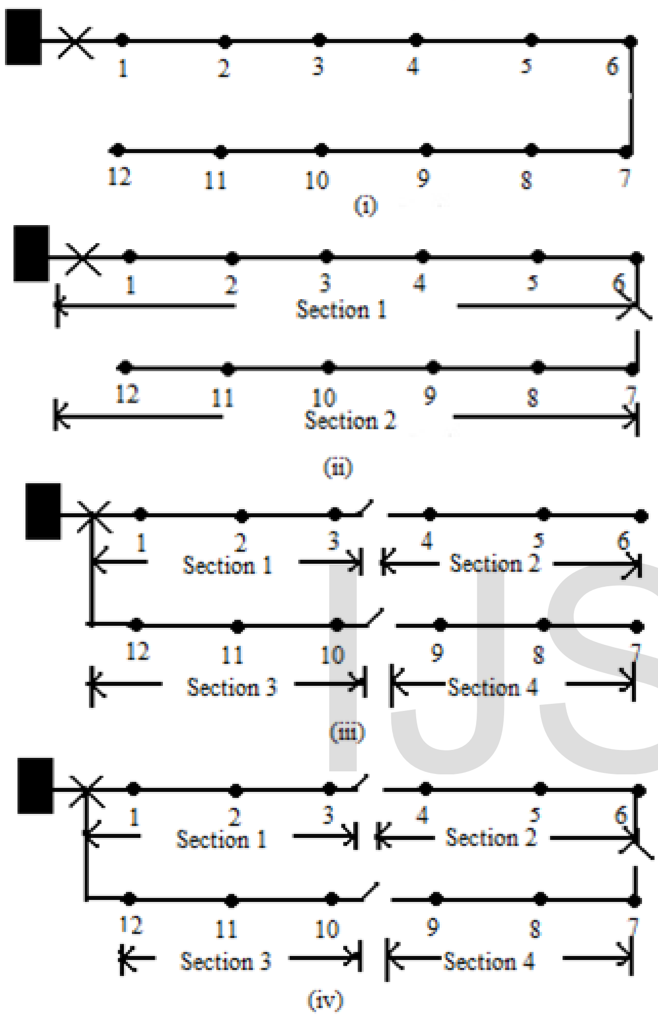

Fig: 4 Radial networks with sectionalizing switches at different locations

4.5. Location of Sectionalizing Switches:

The location of sectionalizing switches is determined based on Reliability index. The reliability of the distribution network is evaluated by a reliability index, i.e., contingency-load-loss index (CLLI)[2], defined as the ratio of the average non-delivered load due to failure of all branches, taken one at a time, to the total load.

The computation of the CLLI is illustrated with four possible network structures as follows:

Node 1 is the substation and every other node has 100 kW load (assumed). In Fig. 1(a), for a fault in any branch, the circuit breaker will isolate all the nodes from the supply. Thus, the total non-delivered load for a branch fault will be 1200 kW. Since any branch fault results in the same total non-delivered load, the average non-delivered load for all the branch faults, taken one at a time, is: (1200 × 12)/12 = 1200 kW. Thus, the CLLI for this network is 1. This is the maximum possible value of CLLI; hence this is the least reliable network from the non-delivered load point of view. In Fig. 1(b) with one sectionalizing switch (normally closed) between the nodes 7–13, the network has two sections, i.e., Sects. 1 and 2. For a fault in any branch of Sect. 2, the switch can be opened to maintain the supply to Sect. 1 and it causes a non-delivered load of 600 kW. But, a fault in Sect. 1 results in a total non-delivered load of 1200 kW. As each section has six branches, the average non-delivered load is: (6 × 1200 + 6 × 600)/12 = 900 kW and the CLLI for this network is 900/1200 = 0.75; thus this network is more reliable than that of Fig. 1(a). For Fig. 1(c), the CLLI is {(2 × 3 × 300 + 2 × 3 × 600)/12}/1200 = 0.375 and this network is more reliable than the single feeder radial networks. For Fig. 1(d), the CLLI is 0.23; thus this network is the most reliable amongst all.

The conductor types, substation sizes, and the circuit breaker types are chosen from pre-defined sets. The breaker types are decided based on the short circuit capacity of the networks. The simultaneous optimization of the two objective functions in this planning problem is performed as they conflict with each other due to the following factors:

- *Network structure*: A meshed network is more reliable but costlier than a radial net-work due to more number of branches and costly breakers/switchgears for higher short circuit level.
- *Sectionalizing switch*: It improves the CLLI; but its cost increases the objectivefunction.

5 RESULTS

5.1. Results obtained using Particle decoding

5.1.1 Obtained Network:

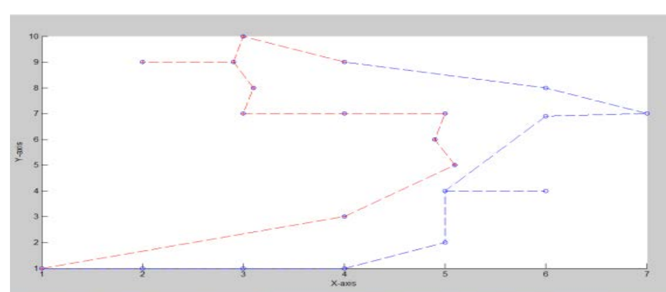

Fig no: 5.1 Network obtained using Particle decoding method

5.1.2 Graphs Between 'Best cost vs No. Of Iterations & Best Fitness vs No. Of Iterations':

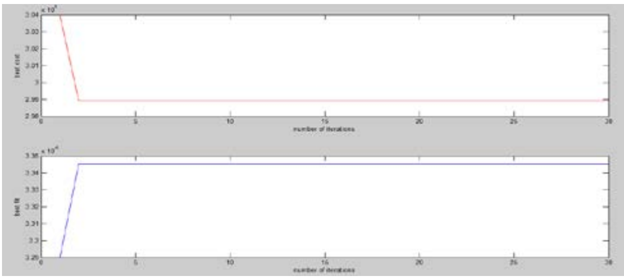

Fig no: 5.2 Graphs obtained b/w "Best cost vs no. of iterations and best fitness vs no. of iterations

5.1.3 Cost of Each Radial Path in $

Cost of Radial Path1=156370$

Cost of Radial Path2=164630$

5.1.4 Current Tapping Values Obtained At Each Node And Maximum And Minimum Values Of Current Are As Shown in Table 1:

Node No.	Current Value (A)	$I_{min(A)}$	$I_{max(A)}$
1	0	0	0
2	15.4007	14.9102	17.5033
3	7.6862	7.4551	8.7517
4	11.6083	11.1827	13.1275
5	15.4007	14.9102	17.5033
6	19.2093	18.6378	21.8792
7	3.9587	3.7276	4.3758
8	7.6862	7.4551	8.7517
9	15.4007	14.9102	17.5033
10	39.0448	37.2756	43.7583
11	68.9171	67.0961	78.7650
12	7.6862	7.4551	8.7517
13	7.6862	7.4551	8.7517
14	15.1413	14.9102	17.5033
15	7.6862	7.4551	8.7517
16	31.3378	29.8205	35.0067
17	56.6497	55.9134	65.6375
18	7.6862	7.4551	8.7517
19	7.6862	7.4551	8.7517
20	7.7611	7.4551	8.7517
21	7.6862	7.4551	8.7517

Table No.1

5.2 Results Obtained Using $^{N}C_{R}$ Method

5.2.1 Network Obtained:

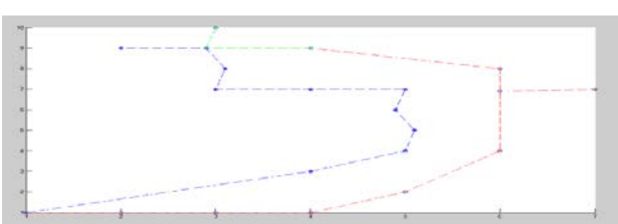

Fig no: 5.3 Network obtained using from all possible combinations

5.2.2 Graphs Between 'Best Cost vs No. of Iterations & Best Fitness vs No. of Iterations':

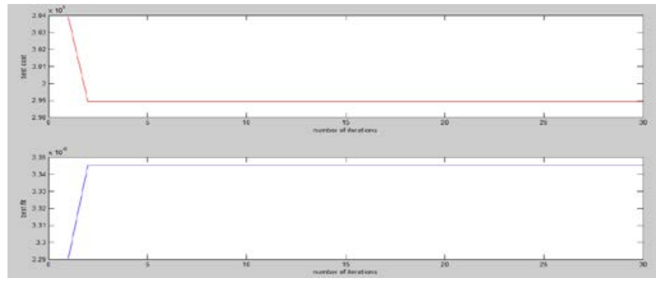

Fig No: 5.4 Graphs b/w "best cost vs no. of iterations and best fitness vs no. of iterations

5.232 Cost of Each Radial Paths in $:

Cost of Radial Path1=149000$

Cost of Radial Path1=154930$

5.2.4 Current Tapping Values Obtained At Each Node And Maximum And Minimum Values Of Current Are As Shown In Table 2:

Node No.	Current Value (A)	$I_{min(A)}$	$I_{max(A)}$
1	0	0	0
2	16.2591	14.9102	17.5033
3	7.8159	7.4551	8.7517
4	11.6083	11.1827	13.1275
5	15.4007	14.9102	17.5033
6	20.2499	18.6378	21.8792
7	4.0235	3.7276	4.3758
8	7.8159	7.4551	8.7517
9	15.4007	14.9102	17.5033
10	39.7823	37.2756	43.7583
11	70.2055	67.0961	78.7650
12	7.8159	7.4551	8.7517
13	7.8159	7.4551	8.7517
14	15.4007	14.9102	17.5033
15	7.8159	7.4551	8.7517
16	31.9010	29.8205	35.0067
17	56.9449	55.9134	65.6375
18	7.8159	7.4551	8.7517
19	7.8159	7.4551	8.7517
20	7.7677	7.4551	8.7517
21	7.8159	7.4551	8.7517

Table No.2

5.2.5. CLLI:

Obtained CLLI value obtained for the mesh network is 0.2335

6 Conclusion

The typical 21 node distribution system has been reduced to 2 optimal radial networks using Particle Decoding & PSO and Number of Combinations & PSO methods. As the no. of nodes increases the size of connectivity matrix increases and particle

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decoding methods becomes difficult. So, getting shortest path from finding all combinations i.e. no. of combinations method and then applying PSO for optimizing current tapping values at every node is better when compared to Particle Decoding & PSO method. The reliability is same in both the cases.

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