International Journal of
Intelligent Systems and Applications in Engineering

ISSN:2147-6799 www.ijisae.org Original Research Paper

Optimal Power Distribution Planning Using Improved Particle Swarm Optimization

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Accepted : 04/06/2018 Published: 28/09/2018

Abstract: In planning of radial power distribution system, optimal feeder routing and optimal branch conductor selection plays an important role. Economical distribution system requires effective planning method, which involves optimization procedure to connect the given load to the substations. In the paper, a generalized algorithm is developed for obtaining the optimal feeder path and the optimal location of substation on minimum loss criterion. Forward/Backward sweep load flow technique is applied to calculate the energy loss costs and select the minimum energy loss cost path for the power distribution. Finally, the optimal branch conductor selection of radial distribution system is performed by using particle swarm optimization (PSO). The proposed method has been tested on several radial distribution systems and results were found encouraging.

Keywords: *Path selection, Conductor selection, Optimization, Load Flow method, Optimal Planning*

1. Introduction

Designing a distribution network optimally requires number of technically feasible alternatives and utilization of enhancement tools [1]. The choice of options and streamlining apparatus rely upon the demands with worthy unwavering quality levels, power transportation breaking points of distribution lines and the radial structure of the network [2].The issue of distribution framework planning is to locate the optimum substation location and the faultless feeder configuration to connect the load to the substation [3].

The distribution system planning is huge to give reliable and cost effective operation to consumers [4]. The planning issue of distribution networks might be expressed as an improvement issue, so that for a given geographical area or region with an arrangement of load demands already evaluated, the attributes of the network are resolved, including the area of the transformation centres, limiting the total installation and operation costs, subject to the technical requirements for a satisfactory operation of the system [5]. To deal with such issues new optimization tools and frameworks are basic considering the range and size of substations and feeders, the improvement of new feeders and furthermore new substations [6].

Power distribution planning is a complex problem for the researchers. There are two approaches used for solving this complex problem, i.e classical search algorithm and evolutionary algorithm. Now a day's researcher have used different evolutionary algorithm for planning a optimal power distribution system because EA is superior over classical approach. There are different types of EAs, e.g PSO, GA, ACO, AIS and Tabu Search.

In earlier literature GA has been mostly used for the power distribution planning but the recent literature survey indicates that the PSO is a powerful challenger of the GA [7].

In this paper multi objective planning problem is solved by using particle swarm optimization (PSO). This problem involves a number of planning variables such as: optimal location of substation, optimal feeder path and optimal selection of conductors. These planning objectives are achieved by minimizing the objective function which consists of installation cost of new facility (substation and feeder) and energy loss cost. The association of this paper presents the related work is section 2, the proposed distribution system planning algorithm in section 3, the simulation results of the proposed work in section 4 took after by the conclusion in section 5.

2. Related Work

Mostafa Esmaeeli et al. [8] have proposed a risk-based planning technique in LV distribution networks for ideally deciding the size, number, and the situation of distribution transformers. In that approach, three different risk techniques are characterized for distribution system operator (DSO). They are named risk-seeker, risk-neutral, and risk-averse.

Marina Lavorato et al. [9] have proposed a constructive heuristic algorithm (CHA) to comprehend distribution system planning (DSP) issue. The DSP is a particularly complex mixed binary nonlinear programming issue. A CHA was aimed to get an awesome quality response for the DSP issue. The proposed method has been tested on two test systems and one real system.

Singh et al.[10] presented a simple and easy method for power distribution planning without using any optimization technique. But the limitation of this method is that the connection of new node is dependent upon the sequence of appearance of node in data file.

Amin Hajizadeh and Ehsan Hajizadeh [11] presented a multiobjective planning algorithm based on PSO for optimal siting and sizing of DGs in radial distribution systems by minimizing the objective function. The algorithm has been tested on IEEE 33 bus system.

Mohammadian et al.[12] presented a PSO based algorithm for

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practical planning of radial distribution systems includes optimal selection of conductor and placement of capacitor in radial distribution system.

3. Optimal Power Distribution System Planning

This paper provides an optimal power distribution in the following stages, initially all the possible paths are identified using the uploaded system data and then for each identified path forward/backward sweep load flow technique is applied to calculate the energy loss costs. The minimum energy loss cost path is selected for the power distribution. Then the optimal branch conductor selection of radial distribution system is performed by using particle swarm optimization (PSO). Here, the optimization is improved by the parameters such as power loss, voltage profile and Depreciation on capital investment. The PSO optimization results the optimal conductor and the location of the optimal conductor is chosen as the optimal substation and then through the optimal substation power distribution. The block diagram of proposed work is given in figure1.

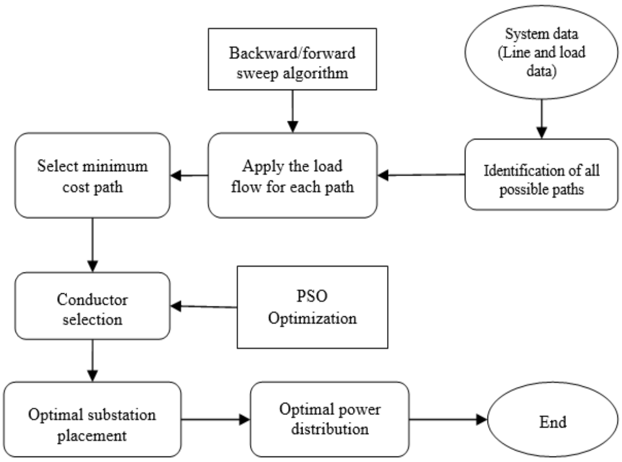


Figure 1. Block diagram of proposed optimal power distribution

3.1. Identification of all possible paths

In the proposed method, all possible radial paths are initially identified by the following steps. Let us consider an '*n*'-node distribution network. The path selection algorithm has following steps [13]:

- Initiate from the substation node (let node -1), check the nodes which are directly connected to substation node and form a connection matrix '*q*'.
- Check the last node's connections of '*q*'matrix and update matrix with new connections.
- Updated node's connections are entering in new rows of matrix '*q*'.
- Repeat the second and third step for next iteration until last node having no remaining connection. So in this way all possible radial paths for energizing all nodes (2 to n -node) are obtained.
- Now separate possible paths for respective energizing nodes (2 to n -node) i.e. create *n-1* matrices $q_2, q_3, \ldots q_{n-1}$. Row of matrices represents the path for energizing node.

3.2. Load flow on each path

The load node for each possible paths matrix represented by $q_2, q_3, \ldots q_{n-1}$. To calculate the energy losses in each path of respective load node, the forward/backward sweep load flow technique is used [14].

Let $V_1, V_2, V_3, \ldots\ldots$ and V_n are the bus voltages, $I_1, I_2, I_3, \ldots\ldots$ and I_p are the line currents, $S_1, S_2, S_3, \ldots\ldots S_n$ is the bus load, n is the number of buses in the system and p is the number of lines in the system.

The steps of the algorithm are as follows

Step: 1 Assign a flat voltage profile for all network nodes $V_i = 1.0$ for $i = 2\, to\, n$ and for substation or root node $(n=1)$ $V_1 = V_{spec}$, where V_{spec} is the specified voltage at root node.

Step: 2 Initially $k = 0$, Set iteration count $k = k+1$.

Step: 3 calculate the nodal current injections

$$J_i^{(k)} = \left(S_i \Big/ V_i^{(k-1)} \right)^* \quad \text{for } i = 2\, to\, n \tag{1}$$

Starting from the end nodes and moving towards the root node calculate the branch currents.

$I_j^{(k)} = J_i^{(k)} + \sum$ Currents in the branches connected to node i for all $j = 1\, to\, p$.

This is backward sweep which is application of Kirchhoff's current law at each node.

Step: 4 Starting from the root node and travelling towards the end nodes calculate the node voltages.

$$V_i^{(k)} = V_j^{(k)} - Z_j I_j^{(k)} \text{ for } \text{i=2 to n} \tag{2}$$

Z_j is the impedance of the line j connecting i^{th} and j^{th} node. This is forward sweep and is application of Kirchhoff's voltage law.

Step: 5 Calculate the maximum mismatch in the bus voltage

$$\Delta V_{\max} = \max(abs(V_i^k - V_i^{k-1})) \text{ For i=2 ton} \tag{3}$$

If $\Delta V_{\max} > \varepsilon$, then repeat the steps from 2 to 5.

If $\Delta V_{\max} \le \varepsilon$ then the algorithm has converged.

Where ε is the maximum voltage mismatch, V_i^{k-1} is the node *n* voltage in previous iteration, V_i^k is the node *n* voltage in current iteration.

3.3. Implementation of PSO for Optimal Conductor Selection

3.3.1. Particle swarm optimization (PSO)

Particle Swarm Optimization (PSO) algorithm is developed by Kennedy and Elbehart in 1995 [15]. PSO is initialized by population of random solutions called as particles and updating themselves continuously. Over a number of iterations, a group of variables have their values adjusted closer to the member whose value is closest to the target at any given moment. It's an algorithm that's simple and easy to implement.

3.3.2. Performance of particle swarm optimization using inertia weights

Shi and Eberhart in 1998 [16] proposed an inertia weight 'w' to have a better balance between the local and global search. Use of this 'w' has improved performance of basic PSO in many applications.

The following describes the position and velocity update equations with weight factors included.

$$V_{id} = W \times V_{id} + C_1 \times \varepsilon_1 \times (P_{id} - X_{id}) + C_2 \times \varepsilon_2 \times (P_{gd} - X_{id}) \tag{4}$$

$$X_{id} \rightarrow X_{id} + V_{id} \tag{5}$$

where in d dimensional space

X_{id} is present position vector
V_{id} is present velocity vector
P_{id} best position vector
P_{gd} is global best position vector
W is inertia weight
ε_1 and ε_2 are random number generators.
C1, C2 are positive constants.

With a proper selection of 'w' number of iterations also reduces. Hence, it is required to keep the value of 'w' varying and linearly decreasing from 0.9 to 0.4. A large weight factor facilitates a global search while a small inertia weight facilitates a local search. Value of 'w' is determined by using equation (6)[17].

$$W = (w_{max} - w_{min})\left(\frac{iter_{max} - iter}{iter_{max}}\right) \quad (6)$$

Where w_{max} and w_{min} are maximum and minimum values of the inertia weight, $iter$ is the current iteration and $iter_{max}$ is the maximum number of iterations.

3.4. Optimal conductor selection

The load flow analysis designs a system that has a good voltage profile during normal operation and that will continue to operate acceptably when one or more lines become inoperative due to line damage, lightning strokes, failure of transformers, etc. To obtain the optimal conductor, the power loss, voltage profile and depreciation on capital investment of the transmission line is must be low. The objective function is the sum of the conductor annual energy loss cost and the conductor depreciation cost [18]. These are calculated by

$$C = C_f + C_l \quad (7)$$

Where, C_f is annual fixed cost of connected feeder lines and substations, C_l is annual energy losses cost of network.

3.4.1. Calculation of total energy loss cost

The major cost in electrical distribution network is the energy losses cost. The total annual cost of radial distribution network is expressed as:

$$C_l = P_L \,[Kp + Ke \times Lsf \times 8760] \quad (8)$$

Total energy loss cost is calculated for each path by the equation (8) and selects the minimum energy loss cost path as the optimal path.

3.4.2. Power Loss

The real power loss of distribution network is given by

$$P_L = \sum_{j=1}^{N-1} R_j \, I_j^2 \quad (9)$$

Where, j is the branch number, R_j is the resistance and I_j is the current of j^{th} branch, respectively. P_L is the total real power loss of N-bus distribution network.

3.4.3. Depreciation on capital investment:

The annual capital cost for branch j with k type conductor is,

$$C_f = \alpha \times [cost(k) \times len(j)] \quad (10)$$

Where, α is the interest and depreciation factor, cost(k)is the cost of k type conductor (Rs/km), len(j) is the length of branch j in (km)

3.5. PSO optimization algorithm

PSO is an optimization tool can solve an assortment of difficult optimization issues. In this paper the optimal power distribution is obtained using the PSO algorithm. The detailed algorithm to determine optimal conductor is given below,

Step 1: Initialize the system data and population size.
Step 2: Perform load flow.
Step 3: Set the iteration count to '1'.
Step 4: The objective is to select optimal size of the conductor in each branch of the path, which minimizes the total cost. From equation (7) the overall objective function can be calculated.
Step 5: The evaluation of fitness function is a procedure to determine the fitness of each string in the population. Since the PSO proceeds in the direction of evolving best-fit strings and the fitness value is the only information available to the PSO, the performance of the algorithm is highly sensitive to the fitness values. The fitness function f is calculated by the following equation.

$$f = \frac{1}{C(objective\ function)} \quad (11)$$

Step 6: If fitness is better than fitness (pbest), replace it. If fitness is better than global fitness (gbest), replace it. **Step 7:** Now update the velocity and position of the particle using equation (4) and (5).
Step 8: Increment iteration count. If iteration $count < \max$. Count, go to Step 3. Else go to Step9.**Step 9** The algorithm results the optimal conductor for each branch. The flow diagram of proposed PSO optimization algorithm is given in figure 2.

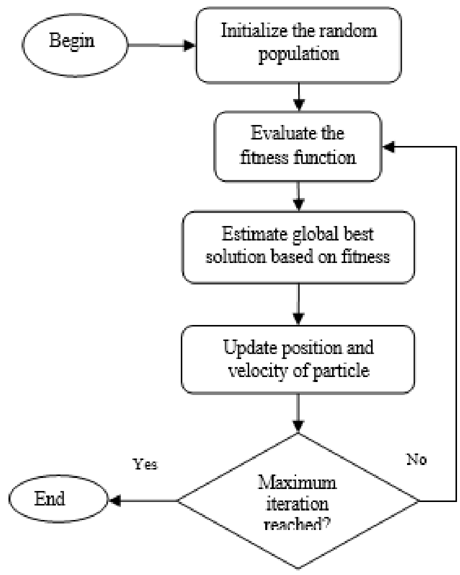


Figure 2. PSO optimization algorithm

The proposed optimization algorithm results the optimal conductor for the power distribution. Location of the optimal conductor is selected as the optimal substation location. Then the total kilovolt-ampere (KVA) fed through a particular optimal substation. Here we pick that the substation is a node. The ideal location for substation is also processed by limiting the power loss.

4. Results and Discussion

The proposed strategy of optimal planning in power distribution system is implemented in the working platform of MATLAB (version 17). The proposed Algorithm is tested on 33 node radial distribution system, 69 node radial distribution system and 54 node radial distribution systems.

4.1. Testing on 33-nodes Radial Distribution Network:

The single line outline of 33-node radial distribution network is appeared in figure 3.

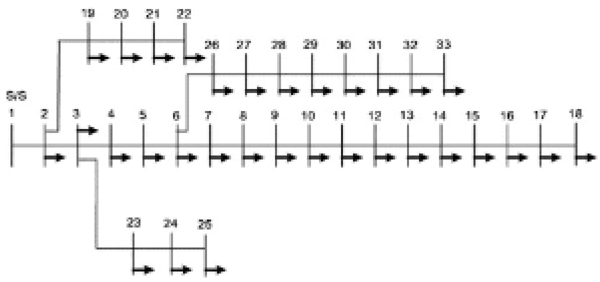


Figure 3. 33 node radial distribution network

Table 1: Results of feeder configurations of 33 node radial distribution systems

Feeder configuration	Real power loss (kW)	Reactive power loss (kVAr)	Min voltage(pu)
Single case	199.2258	135.0840	.9096
Two case	103.9171	70.4605	0.9546
Three case	84.1729	57.0730	0.9635

The results of proposed optimal power distribution planning using improved particle swarm optimization on 33 nodes radial distribution network is tabulated in table1 for single feeder case, two feeder case and three feeder cases. From table 1 we realize that the proposed distribution system planning Algorithm yields a minimum real power loss of 84.1729kW and least reactive power loss of 57.0730kVAr in three feeder case scenario. Furthermore, the minimum node voltage of 0.9635 is acquired in three-feeder case of 33-node radial distribution system. The figure 4 shows the comparison of voltage profile with and without proposed optimized distribution planning Algorithm. The results confirm that the proposed optimized distribution planning algorithm yields improved voltage profile.

Figure 4 demonstrates the voltage profile of 33-node radial distribution system for proposed optimized distribution system with single, two and three feeder arrangements and existing without optimized distribution.

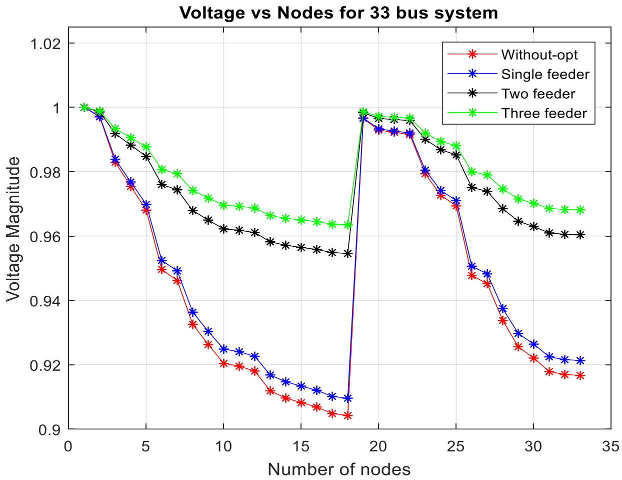


Figure 4. Voltage profile of 33 node radial distribution system

4.2. Testing on 69 node radial distribution network:

To demonstrate the adequacy of the planned technique, a 69-node radial distribution system as shown in figure 5 is considered.

The testing results of proposed optimal power distribution planning using improved particle swarm optimization on 69 nodes radial distribution network in terms of total real power loss, total reactive power loss and minimum voltage is given in table 2. The performance is also analyzed for single feeder case, two feeder case and three feeder cases.

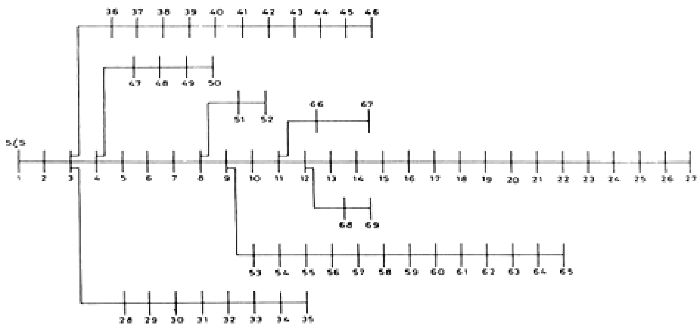


Figure 5. 69-node radial distribution network

Table 2: Results of single, double and three feeder configurations of 69 node radial distribution systems

Feeder configuration	Real power loss (kW)	Reactive power loss(kVAr)	Minimum feeder voltage(pu)
Single case	217.4829	98.6441	0.9152
Two case	113.4401	51.4535	0.9573
Three case	91.8865	41.6773	0.9657

From table 2 it is clear that the proposed distribution system planning Algorithm yields a minimum real power loss of 91.8865kW and least reactance power loss of 41.6773kVAr in three-feeder case of 69 node radial distribution systems. The minimum node voltage of 0.9657 is obtained in three-feeder case. The figure 6 shows the comparison of voltage profile with and without proposed optimized distribution Algorithm, The comparison results prove that the proposed optimized distribution planning results the improved voltage profile than the existing without optimization Algorithm

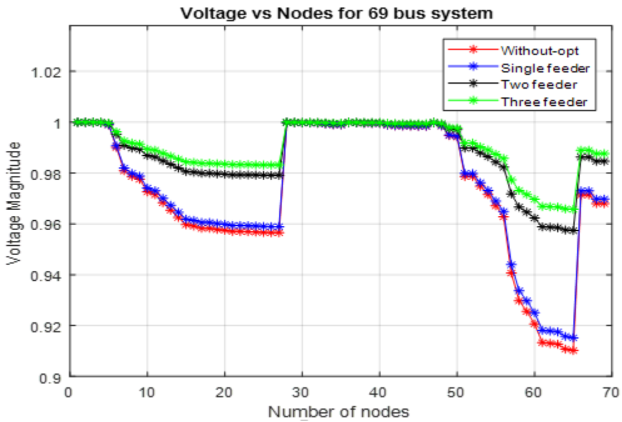


Figure 6. Voltage profile of 69 node radial distribution system

4.3. Testing on 54-nodes Radial Distribution Network

For established the effectiveness of the proposed Algorithm another test system is considered that has been used and reported by many researchers using different technique such that Knowledge Based Expert System [3], ACS [5] and PSO [19]. The single line outline of 54-node radial distribution network is shown in figure.7

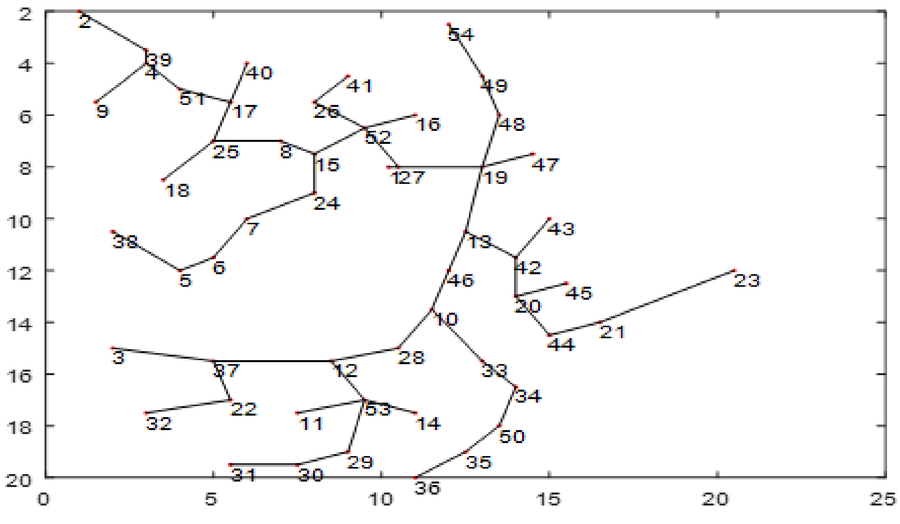


Figure 7. Optimal feeder configuration for single feeder

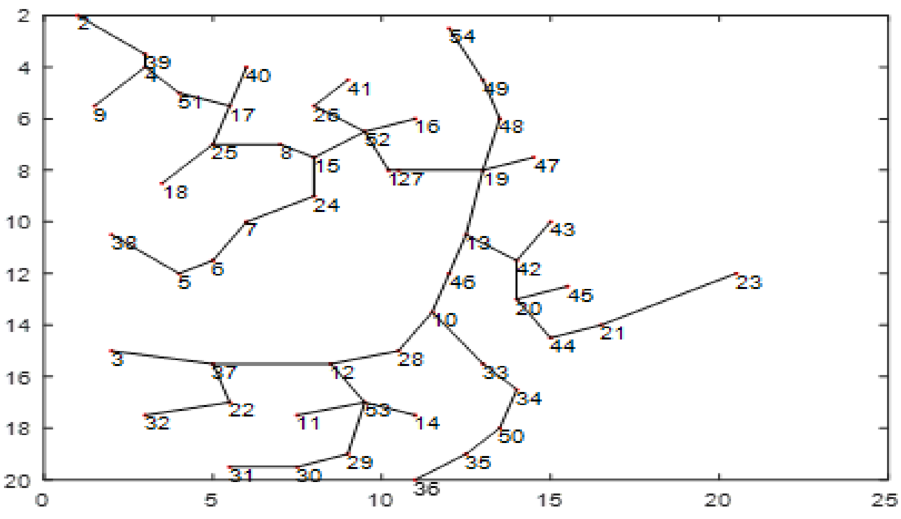


Figure 8. Optimal feeder configuration for two feeder

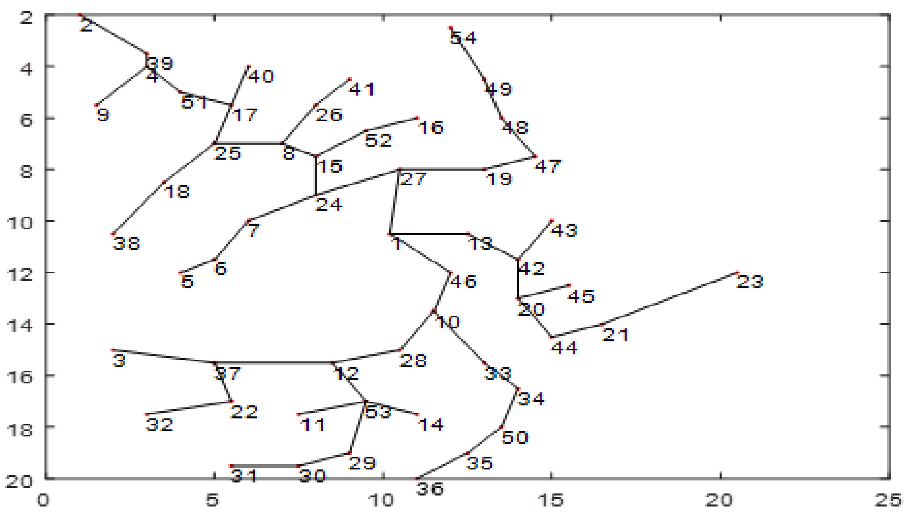


Figure 9. Optimal feeder configuration for three feeders

Table 3: Detailed Results of single feeder configurations of 54 node radial distribution systems

Branch no.	Sending	Receiving	R (ohm)	X (ohm)	TYPES	Real Power Loss (kW)	Current (A)	Cost (RS)
1	39	2	3.44	0.974	Squirrel	0.0188	2.4325	1666
2	37	3	4.184966	1.184929	Squirrel	0.0238	2.6232	2027
3	51	4	1.945939	0.550972	Squirrel	0.3245	13.4404	1845
4	6	5	1.538368	0.435573	Squirrel	0.1341	9.6794	1108
5	7	6	2.480653	0.702371	Gopher	0.4577	15.7991	2785
6	24	7	3.076874	0.871185	Weasel	0.9033	21.9308	4749
7	15	8	1.538368	0.435573	Mink	0.6061	35.8964	3891
8	4	9	2.918909	0.826458	Squirrel	0.016	2.4307	1414
9	46	10	2.175594	0.615997	Beaver	2.2313	67.2292	10091
10	53	11	2.836762	0.803199	Squirrel	0.0066	1.6774	1348
11	28	12	2.836762	0.803199	Mink	1.4068	43.0465	7875
12	19	13	3.508112	0.993285	Raccon	8.9918	109.9756	35007
13	53	14	2.175594	0.615997	Squirrel	0.0784	6.6172	1240
14	52	15	2.480653	0.702371	Beaver	3.4504	74.2368	14839
15	52	16	2.175594	0.615997	Squirrel	0.0115	2.338	1054
16	25	17	2.175594	0.615997	Weasel	0.5234	19.8682	3037
17	25	18	2.918909	0.826458	Squirrel	0.0064	1.5404	1387
18	27	19	3.44	0.974	Raccon	11.8623	127.0068	45135
19	42	20	2.064	0.5844	Weasel	0.4267	18.8757	2702
20	44	21	2.175594	0.615997	Squirrel	0.1087	7.5376	1343
21	37	22	2.175594	0.615997	Squirrel	0.0496	5.2491	1165
22	21	23	6.15361	1.74233	Squirrel	0.1369	5.0366	3293
23	15	24	2.064	0.5844	Rabbit	0.75	31.5337	4699
24	8	25	2.752	0.7792	Ferret	1.2099	31.188	6178
25	52	26	2.480653	0.702371	Squirrel	0.3282	11.7405	2139
26	1	27	0.4128	0.11688	Raccon	4.5797	216.8901	15928
27	10	28	2.480653	0.702371	Beaver	1.3035	48.2265	7996
28	53	29	2.836762	0.803199	Gopher	0.4729	16.0075	3068
29	29	30	2.175594	0.615997	Squirrel	0.3168	13.3418	1962
30	30	31	2.752	0.7792	Squirrel	0.1003	6.6672	1589
31	22	32	3.508112	0.993285	Squirrel	0.02	2.6247	1704
32	10	33	3.44	0.974	Gopher	0.6785	17.1088	4052
33	33	34	1.945939	0.550972	Squirrel	0.2353	11.9278	1617
34	50	35	1.945939	0.550972	Squirrel	0.0438	5.1408	1043
35	35	36	2.480653	0.702371	Squirrel	0.014	2.5698	1205
36	12	37	4.816	1.3636	Squirrel	0.6854	13.1812	4312
37	5	38	3.44	0.974	Squirrel	0.0751	4.8441	1837
38	4	39	0.688	0.1948	Squirrel	0.0467	8.5562	461
39	17	40	2.175594	0.615997	Squirrel	0.0118	2.4166	1055
40	26	41	1.945939	0.550972	Squirrel	0.0103	2.3438	943
41	13	42	2.480653	0.702371	Ferret	0.8954	28.9451	5046
42	42	43	2.480653	0.702371	Squirrel	0.0544	4.9818	1328
43	20	44	2.480653	0.702371	Squirrel	0.2201	10.0497	1830
44	20	45	2.175594	0.615997	Squirrel	0.012	2.4967	1056
45	13	46	2.175594	0.615997	Beaver	2.6871	73.6986	12147
46	19	47	2.175594	0.615997	Squirrel	0.0737	6.0167	1243
47	19	48	2.836762	0.803199	Squirrel	0.2013	8.7231	1939
48	48	49	2.175594	0.615997	Squirrel	0.0813	6.3243	1266
49	34	50	2.175594	0.615997	Squirrel	0.0853	6.7875	1278
50	17	51	2.175594	0.615997	Gopher	0.4035	15.88	2483
51	27	52	2.480653	0.702371	Beaver	5.1036	90.2867	20591
52	12	53	2.480653	0.702371	Ferret	0.727	27.0175	4539
53	49	54	3.076874	0.871185	Squirrel	0.066	4.7931	1643

The testing results of proposed Algorithm on 54node radial distribution systems with single feeder cases are shown in table3 and the comparative results of various feeder and with reported Algorithm [3] is given in table4 and table5.

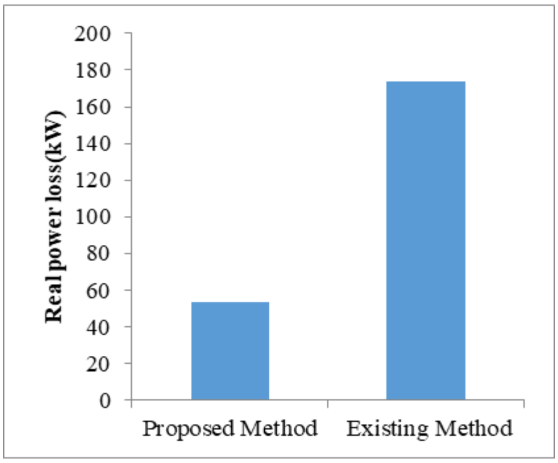
Table 4: Comparative Results of feeder configurations of 54 node radial distribution systems of various configuration (Proposed Algorithm).

Feeder configuration	Real power loss (kW)	Total cost (Rs.)	Min. voltage(pu)
Single case	53.268	267178	0.8606
Two case	49.6355	255220	0.8969
Three case	41.2776	232150	0.9035

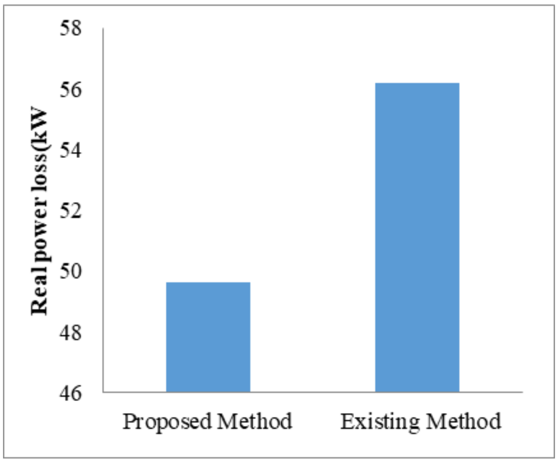
From table 4 and table5 we realize that the proposed distribution system planning method yields a minimum real power loss of 41.2776kW and least system cost 232150Rs. in three feeder case of 54 node radial distribution system. The performance comparison graph of proposed Algorithm with reference [3] is given in figure 6

Table 5: Comparative Results of real power loss of 54 node radial distribution systems of various configuration with proposed Algorithm and reported Algorithm [3].

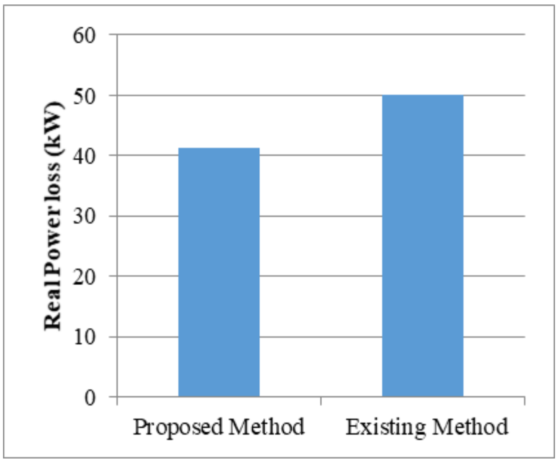
Feeder configuration	Real power loss (kW) (Proposed Algorithm)	Real power loss (kW) as per Ref.[3]
Single case	53.268	173.5
Two case	49.6355	56.18
Three case	41.2776	50.12



(a) Single feeder



(b) Two feeder



(c) Three feeder

Figure 10. Performance comparison on 54 node radial distribution network in terms of real power loss

5. Conclusion

In this paper optimal power distribution planning algorithm is proposed using improved particle swarm optimization (PSO) technique. Initially, algorithm is developed for obtaining the optimal feeder path, optimal location of substation based on minimum loss criterion. Then, the optimal branch conductor selection of radial distribution system is performed using particle swarm optimization (PSO). The optimization algorithm is improved by using the power loss and depreciation on capital investment parameters. The effectiveness of the proposed algorithm is tested on 33node, 69 node and 54 nodes radial distribution network with single and multiple feeder cases. The results are compared with the other reported methods and found effective.

6. References

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