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A Technique of Global Optimal Solution for Radial Distribution System by Using Load Flow Analysis

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Abstract: ***This paper proposes the application of Direct Approach algorithm for feeder routing of radial distribution system. For which a complete network of available routes is considered and the optimization goal is to find the routes that provide the minimum number of energizing nodes for existing network and load flow analysis for the same network. The feasibility of proposed algorithm is applied on 25 nodes and 24 branches distribution network. This paper proposes a simple direct solution that significantly reduces the inherent difficulties of finding the solution and ensures optimum solution at the same time. Moreover, the concept of optimality is effectively used to make the proposed technique more computationally efficient and useful.This approach builds on simple concept that depends solely on tracking of radial paths and calculating losses associated with the paths. An easy step by step building algorithm is proposed to find the radial paths existing in a system. The work has also explored the advantage of optimality and successfully established a link with radial system planning that makes the process of searching faster and more effective. The proposed technique ensures global optimal solution without being influenced by initial paths as considered in classical techniques or different parameters as required by soft computing techniques for tuning. Along with the routing, the solution of load flow is also proposed.***

Keywords: Distribution system planning, direct solution approach, optimality, load flow analysis

1. Introduction

Distribution system planning is important to ensure that the growing need of electricity is satisfied by the distributors. Planning starts at customer level, distribution system directly connected to customer any failure in the system would affect the customers. Therefore proper planning of the distribution system is very important for continuity of power. Distribution System Planning involves optimal selection of feeder routes, number of feeder, substation size and location [1]. In this work selection of optimal feeder routes is obtained by the proposed method. Several optimization techniques have been implemented to solve the problem of feeder routing. In the past mathematical approach were applied such as branch and bound method for the optimization of distribution system [2], mixed integer programming [3] applied to the distribution system problem was found feasible, [4] solved the optimal feeder routing using dynamic programming and geographical information systems GIS facilities, which is effective. Another tool to achieve the optimization goal is ant colony system algorithm (ACS) [5]. This methodology is meta-heuristic in nature and is very flexible, robust in minimizing the investment cost. The reduction in the cost during the planning of distribution system, meeting the constraints is obtained by branch exchange method [6]. The effectiveness of Genetic Algorithm [7-9] is seen in the designing of the distribution system by reducing the solution time. Simulated annealing [10] is also proven to be feasible in planning of the distribution network. In this method the minimum cost solution is obtained by steepest descent approach, further the obtained solution is modified by simulated annealing. This method is faster, taking less consumption time. In this paper Direct Approach algorithm is the solution strategy for the optimal feeder routes in the planning of the radial distribution system. Direct Approach algorithm is shortest route algorithm [11] that considers the determination of the minimum distance from an origin to a destination through some connecting graph, used in designing the distribution network. The efficiency of the algorithm is proven in power system restoration [13]. The faulty section is isolated by the proposed algorithm and the supply is restored in the system. The Direct Approach method is superior because it depends more on the number of arcs than nodes. The proposed algorithm works on directed weighted graph and the edges should be non- negative. The optimal routes are obtained to minimum number of energizing nodes for existing network the current and voltage values are needed. For this load flow analysis is solved [14-15]. The following sections describe the problem statement, details on the proposed algorithm, load flow algorithm to obtain the current and voltage for further proceeding in the optimization, results obtained by the algorithm used and the conclusion of the work done.

2. Proposed Algorithm

The direct solution technique is basically based on searching the optimum path for a node among all the possible paths. Starting from a substation there may be many possible radial paths to reach a node. Then the minimum cost path among all the radial paths for feeding a particular node will be the optimum path for the node. For this Direct Approach Algorithm is used. This algorithm solves as a shortest-route problem that considers the determination of the minimum distance (energizing nodes) from an origin to a destination through some connecting graph. After tracing of nodes, load flow is applied to find the current to calculate the active, reactive power and losses.

The radial distribution system is always a directed path, where power is directed from a substation to the load nodes. A directed graph is an ordered pair D= (V, A) with V is a set whose elements are called vertices or nodes, and A is a set of ordered pair of vertices, called arcs, directed edges or arrows.

An arc A= (x, y) is considered to be directed from x to y, where y is called head and x is called the tail of the arc. Every arc will be a radial path starting from any substation. Let us consider a network as shown in the Fig. 1 with all possible paths to feed the three load nodes (2, 3, 4) from substation node 1. The dotted lines represent the probable connections to energize the nodes from the substation node 1. A step by step radial path building algorithm developed to determine all the radial paths is summarized below.

Step 1: Initial arcs with substation
This work initiate with development of arc with the load nodes connected directly with substation. Therefore, the number of initial arcs depends on the number of feeders coming out from the substation. In an arc (x, y), x (tail) will be the substation and y (head) will be the set of load nodes that are connected with x. Y= (y1, y2 … yn) where, y is set of load nodes directly connected with substation x. Thus there are n numbers of arcs after first step that can be written as

A= {(X, y1), (X, y2)………(X, yn)

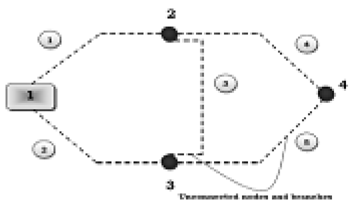

Figure 1: 4-node supply system

Referring to the Fig. 1, we can write

A= {(1, 3), (1, 2)}

Where
X is Substation node 1
Y is a set consisting of load nodes 2 and 3 which are directly connected with the substation node 1.

Step 2: New arcs by extending load nodes at the next step, load nodes connected with substation node acts as tail(x) of the new arc where in the new head(y) depends on the connectivity with the other nodes. As explained earlier, an arc represents a radial path and therefore a new arc adds only a head at a time with an old arc. While updating an arc, it is to be checked that head does not appear in an existing or old arc. Updating of arcs will be continued till the entire possible load nodes are covered. As in (5), nodes 2 and 3 will now be acting as tails in step 2, to be connected with new heads. From Fig. 1, it is clear that 2 may be connected to 1, 3 or 4. But 1 is already present in initial arcs; therefore 1 will not be appearing in a new arc. With node 2, updated arcs are{(1 2 4), (1 2 3)}, similarly with node 3, updated arcs are {(1 3 2), (1 3 4)}. Hence, New updated A= {(1, 3), (1, 2), (1 2 4), (1 2 3), (1 3 2), (1 3 4)}. The continuation of this update will happen till all the four nodes are expanded. Combining all arcs, the final A will be {(1, 3), (1, 2), (1 2 4), (1 2 3),(1 3 2), (1 3 4), (1 2 4 3), (1 2 3 4),(1 3 2 4), (1 3 4 2)}.

Step 3: Zero padding
In this step, set A is converted to equivalent matrix E of specific dimension. In order to maintain same number of elements in each row, zero padding is carried out. Hence, the number of zeros to be entered in each row is calculated using below equation Number of zeros in each row Zp=[(n+1)-Nz] where n is total number load nodes Nz is non zero elements for radial path In matrix form, we can write E1 is

$$
\begin{matrix}
1 & 2 & 0 & 0 \\
1 & 3 & 0 & 0 \\
1 & 2 & 4 & 0 \\
1 & 2 & 4 & 3 \\
1 & 2 & 2 & 0 \\
1 & 2 & 2 & 4 \\
1 & 3 & 3 & 0 \\
1 & 3 & 3 & 4 \\
1 & 3 & 4 & 0 \\
1 & 3 & 4 & 2
\end{matrix}
$$

If there is more than one substation, the same steps 1 to 3 will be followed to construct final E matrix the last load node of its radial path. Node 2 appears three times as last nonzero nodes, therefore, there are three different possible radial paths to energize node2, as represented by a matrix E2 is

$$
\begin{matrix}
1 & 2 & 0 & 0 \\
1 & 3 & 2 & 0 \\
1 & 3 & 4 & 2
\end{matrix}
$$

3. Load Flow

The flow of active, reactive power is known as load flow. Power flow analysis is used to determine the steady state operating condition of the system. The goal of the distribution system power flow function is to study the distribution networks under various loading conditions and configurations. Provided with bus voltage magnitudes and phase angles output from the power flow function, one can derive more information for the distribution network, including real and reactive power flow in each line, line section power loss, and the total real and reactive power at each bus. Radial Distribution Systems (RDS) require special load flow methods to solve power flow equations owing to their high R/X ratio. Hence methods like Newton Raphson cannot be applied. A method name Backward/Forward sweep based on Kirchhoff's current law (KCL) and Kirchhoff's voltage law (KVL) for evaluating the node currents and voltages iteratively is applied for figure 1. In this approach, computation of branch current depends only on the current injected at the neighboring node and the current in the adjacent branch. This approach starts from the end nodes and moves towards the root node during branch current computation.

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Table 1: Optimal paths for all nodes

Node to be energized	*Optimal path*	*Total available radial paths*
15	1-16-17-5-18-15	163
14	1-16-17-5-9-25-14	188
10	1-16-2-6-10	319
13	1-19-4-8-23-11-13	172
22	1-19-20-12-21-22	166
17	1-16-17	224
18	1-16-17-5-18	180
9	1-16-17-5-9	354
25	1-16-17-5-9-25	182
11	1-19-4-8-23-11	231
23	1-19-4-8-23	178
8	1-19-4-8	311
21	1-19-20-12-21	176
12	1-19-20-21	206
20	1-19-20	192
7	1-19-4-7	326
5	1-16-17-5	261
6	1-16-2-6	292
24	1-19-4-24	191
16	1-16	178
19	1-19	210
2	1-16-2	300
4	1-19-4	338
3	1-19-4-23	246
Total radial paths for all nodes		5589
Total shaded paths		1207

The node voltage evaluation begins from the root node and moves towards the nodes located at the far end of the main lines that is to the end nodes. This method is also known as ladder iterative method.

4. Results and Discussion

To check the feasibility of the proposed method, it is applied on distribution system. The graph of available network routes for a rural 10 kV network that should be planned is displayed in Fig: 2. there are 25 load points (transformers 10 kV/0.4 kV) and 24 available routes Segments/branches for their supply from the source 35 kV/10.5 kV Substation at node 1.Total load in the network is 2.55 MVA. The active, reactive power and losses are determined by using Load flow analysis.

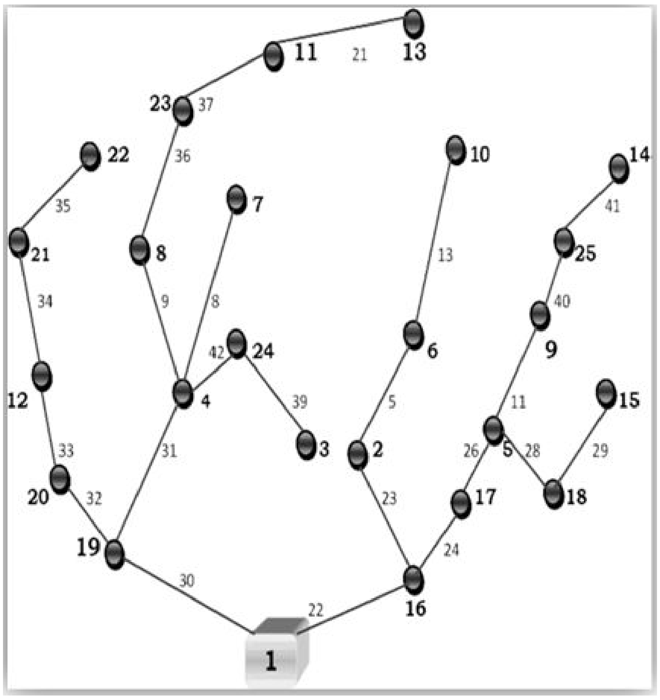

Figure 2: optimal network structure of the 24 load nodes distribution network

5. Conclusion

The planning and design model of distribution, the aim to obtain optimal feeder route and to minimize the number of energizing nodes. The proposed algorithm, direct approach Algorithm is proven to be effective for finding the minimum route from the substation to the demand side. The computational efficiency and speed of Backward and Forward load flow in distribution system is relatively good compared to the classical methods. Due to the simplicity in the load flow, it is widely used. From the test result on 25 nodes system, it is concluded that the proposed algorithm is effective for obtaining the optimal feeder route and reduces the computational time. Hence the use of direct approach algorithm can be applied for distribution system planning.

6. Future Scope

The direct approach method is applied for any number of node system and feeders for optimal power flow in that distribution network. And also it is very easy to obtain optimal feeder route and to minimize the number of energizing nodes. The proposed algorithm, direct approach Algorithm is proven to be effective for finding the minimum route from the substation to the demand side.

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