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Research Article

Power System Restoration in a Distribution Network using Floyd's Algorithm

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Abstract

The present paper describes the implementation of a graph theory based methodology called Flyod's algorithm for an electric power distribution network (PDN). The algorithm is based on finding shortest path between nodes in a weighted undirected graph. An optimal switching sequence is obtained using Floyd's algorithm, by considering the reliability of the entire PDN even during varying load conditions. The proposed methodology are tested and evaluated on a distribution system whose results are presented systematically.

Keywords: Power distribution network; Floyd's algorithm; Power System; Mathematical programming.

Introduction

The distribution systems are generally built as interconnected mesh networks. While in operation, they are arranged in the form of radial line structures. This suggests that the distribution systems are divided into a number of subsystems of radial feeders, which contain a number of normally closed switches (sectional switches) and normally opened switches (tie line switches). These tie switches are being operated during the conditions of maintenance, dispatching and abnormal conditions. By changing the status of feeder switches, the distribution system configuration will be altered and the resulting line currents and losses will be redistributed, with a change in bus voltage. The aim of this switching operation is to improve the reliability and the efficiency of the distribution systems. The power system restoration problem formulation is being discussed in the next section.

Power System Restoration

Whenever power supply interruption occurs in distribution systems due to outage, it is imperative to bring back the system promptly to its initial state or to an optimal target network by switching operations. The problem of obtaining a target network is called as Power System Restoration. The restoration problem is formulated as:

Objective Function

(i) To provide as much service as possible to the affected customers
(ii) To be implemented as fast as possible.
(iii) The restoration solution must be feasible, and that during implementation it should not cause further outages.

Constraints

1. The resulting feeder configuration should remain radial.
2. Line losses should be minimum
3. Service should be restored to all the isolated branches downstream to the affected area.
4. Bus voltages and line currents should be in control
5. The number of switching operations should be within the limit specified by the operators and
6. Line KVA capacity and feeder KVA capacity limits are not violated.
7. Reliable network

Hence the restoration problem is stated as multi objective, multi constraints and combinatorial problem. So the power system restoration is an extraordinary mode of system operation, which requires careful planning and operators training. Subsequently developing an effective and fast service restoration procedure is a cost effective one.

In actual practice, the distribution operators are under immense pressure to restore the out of

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service area as early as possible. In order to help them in the past, considerable efforts have been devoted to the subject of service restoration in distribution systems [1-4]. The problem has been addressed with various methods that can be broadly classified into two groups namely knowledge based method [5-7] and mathematical programming technique. The mathematical programming technique is further classified as optimization methods [8,9] and data structures.

Graph theory [12,13] is a branch of data structures concerned about how networks can be encoded and their properties measured. The paper cited in reference [14] is regarded as the first paper in the history of graph theory.

A graph (G) is a set of points called vertices and lines connecting the points called edges. The graphs are broadly classified into two types. One type of the classification is 'directed graph and undirected graph'. An undirected graph G = (V, E) consists of a finite set of vertices V and a set of edges E. It differs from a directed graph as each edge in E is an unordered pair of vertices. If (v, w) is an undirected edge then (v, w) = (w, v). The other classification is weighted and unweighted graphs. Every path in a weighted graph has an associated path weight, the value of which is the sum of the weights of that path's edges. In this paper the electrical network are analyzed as undirected and weighted graph.

The next term associated with the graph theory is tree which is a collection of elements called nodes one of which is distinguished as a root, which along with a relation places a hierarchical structure on the nodes. The graph can be used for a number of applications, one such application is finding minimum weights from the root node to all the other nodes and the methodology is called as shortest path algorithm and the resultant network is called as minimum spanning tree. A spanning tree is a connected, acyclic sub graph containing all the vertices of a graph. A single graph can have many different spanning trees. A minimum spanning tree or minimum weight spanning tree is then a spanning tree with weight less than or equal to the weight of every other spanning tree.

When a subset T is needed, the number of edges in the graph is E and V is the number of vertices such that the graph remains connected if only the edges in T are used, and the sum of the lengths of edges in T is as small as possible. Such a sub graph must be a tree, and is called a minimum spanning tree

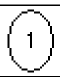
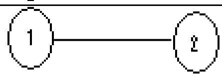
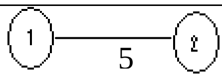
Input: A weighted connected graph G having E edges and V vertices

Output: The set of edges in T comprising a minimum spanning tree of G.

Flyod's Algorithm

Flyod's algorithm is an algorithm in graph theory that finds a minimum spanning tree for a connected weighted graph. Flyod's algorithm is applied for the following sample network with 6 vertices and 10 edges as shown in fig. 1. The vertex 1 is taken as the generation point. The graph shown here is a weighted, undirected network. Table 1 showing all the terms to be known for proceeding through Flyod's algorithm

Table 1. Symbols used in minimum apanning tree

Term	Meaning
	Vertex or node
	The line joining two nodes or vertices is called an edge. Since the line doesn't show the direction it is an undirected graph.
 5	An edge having a weight 5 being connected between the node 1 and node 2

Since it is a weighted graph there are weights given on the edges joining two nodes. The sample diagram is as in Figure 1.

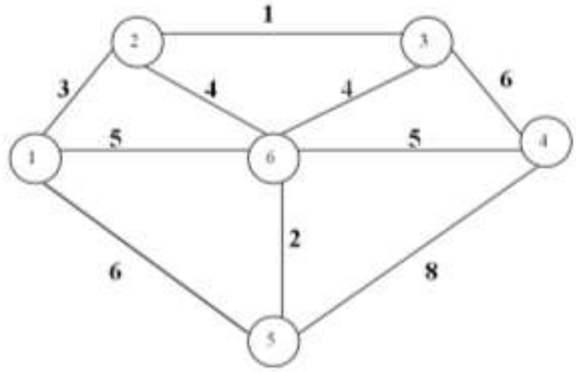


Figure 1. Sample network for example problem

Pseudo code for Floyd's algorithm

```
for k = 1:n // n is the number of nodes
   for i = 1: n
      for j = 1:n
         d(i,j) = min(d(i,j),(d(i,k)+d(k,j)))
      end
   end
end
```

For the given network with 6 nodes the initial distance matrix is

$$D = \begin{bmatrix} 0 & 3 & \infty & \infty & 6 & 5 \\ 3 & 0 & 1 & \infty & \infty & 4 \\ \infty & 1 & 0 & 6 & \infty & 4 \\ \infty & \infty & 6 & 0 & 8 & 5 \\ 6 & \infty & \infty & 8 & 0 & 2 \\ 5 & 4 & 4 & 5 & 2 & 0 \end{bmatrix}$$

After applying the Floyd's algorithm the resultant distance matrix is

$$D = \begin{bmatrix} 0 & 3 & 4 & 10 & 6 & 5 \\ 3 & 0 & 1 & 7 & 6 & 4 \\ 4 & 1 & 0 & 6 & 6 & 4 \\ 10 & 7 & 6 & 0 & 7 & 5 \\ 6 & 6 & 6 & 7 & 0 & 2 \\ 5 & 4 & 4 & 5 & 2 & 0 \end{bmatrix}$$

Here the first row is considered as the resultant matrix, as the starting vertex is considered as 1.

Example System

The Floyd's algorithm based methodology is applied to the sample network. This algorithm reduces the amount of power carried in the distribution lines; as a result, the losses of the entire network get reduced. The algorithm is applied to the system of figure 2 and the results are discussed for the outages single line. Here, the losses need not be separately calculated, because the algorithm developed reduces the entire impedance of the network during restoration. Hence, the losses are minimized. The flowchart of the problem for finding the optimum path from the feeder to all other load points using Flyod's algorithm is shown in figure 3, which indicates how the problem can be solved. The problem is solved using network reconfiguration by operating both the sectional and tie line switches. Since Flyod's algorithm is, a weighted graph theory weights have to be assigned for using the algorithm. The impedance of the respective distribution lines are taken here as weights.

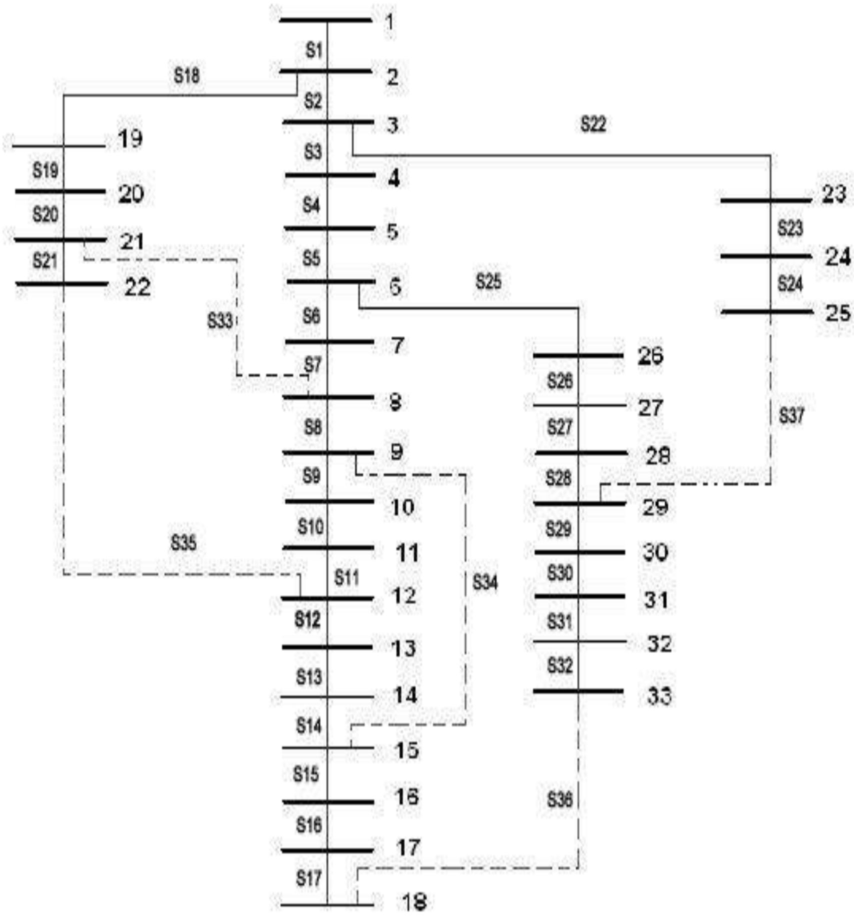


Figure 2. Thirty three bus single feeder distribution network

The original configuration of 33 – bus test distribution network shown in figure 7 has a total load capacity of 3.525 MW and 2.3 Mvar. The network consists of 33 buses and 37 branches, where branches S1 – S32 and S33 – S37 indicate the sectional and tie lines switch respectively. The total impedance of the network for the original configuration having sectional lines is 21.8744+ j 18.1456 and the loss of the network 0.1869 MW and 0.1240 Mvar.

For the given network, the proposed methodology using the four MST algorithms is applied and the switch that should be kept open under normal conditions is tabulated in Table 2. The table indicates the switches those act as tie switches, their total impedance of the resultant network, loss of the network after applying the Flyod's algorithm and minimum p.u. voltage of the network. For the same network hybrid GA [15] and heuristic search method [16] are applied and their results are tabulated in Table 3. Using the proposed methodology for a single line outage in 33 – bus network, the results are obtained and tabulated in Table 4.

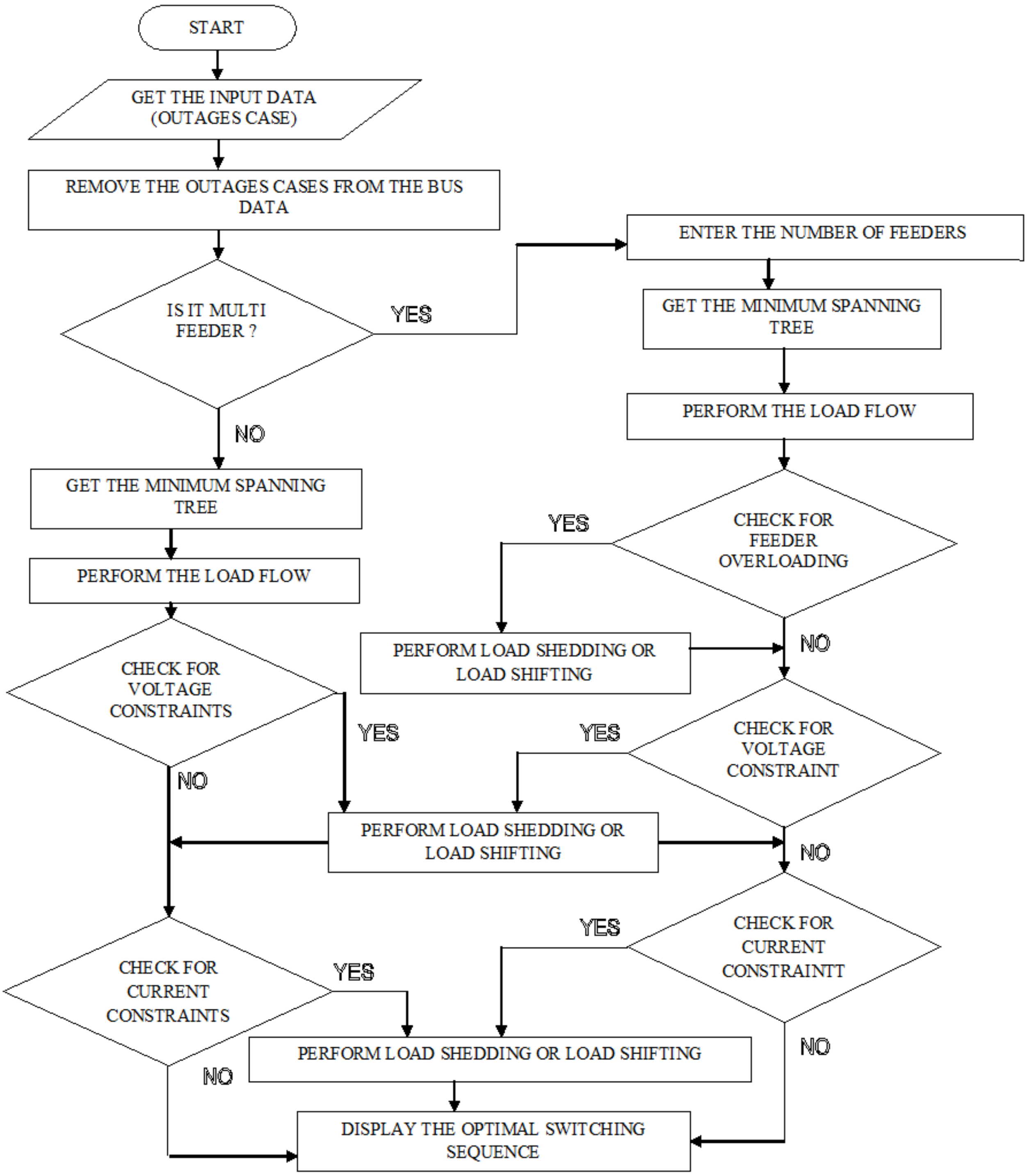


Figure 3. Flow chart of flyod's algorithm

Table 2. Switches that are open and the impedance of the network

Algorithm	Tie Switches					Total Impedance R Ω	Total Impedance X Ω	Real power loss MW	Reactive power loss Mvar	Minimum bus Voltage p.u.
FLYOD'S	S9	S14	S16	S28	S33	26.15	22.46	0.1671	0.1192	0.928

Table 3. Switches that are open and the impedance of the network/ko

Algorithm	Tie Switches					Total Impedance (Ω) R	Total Impedance (Ω) X	Real power loss MW	Reactive power loss Mvar	Minimum bus Voltage p.u.
Refined GA	S7	S10	S14	S36	S37	25.38	22.31	0.2007	0.1776	0.883
Heuristic Method	S7	S9	S14	S32	S37	24.39	21.61	0.1984	0.1760	0.887

Table 4. Result for single line outage in 33 bus network

Outage in line	Switches that are open				
S1	Power system cannot be restored				
S2	S2	S8	S24	S32	S34
S3	S3	S7	S9	S14	S16
S4	S4	S7	S9	S14	S16
S5	S5	S7	S9	S14	S16
S6	S6	S9	S13	S16	S28
S7	S7	S9	S16	S28	S34
S8	S8	S15	S28	S33	S34
S9	S9	S14	S16	S28	S33
S10	S10	S14	S16	S28	S33
S11	S11	S14	S16	S28	S33
S12	S12	S9	S16	S28	S33
S13	S13	S9	S16	S28	S33
S14	S14	S9	S16	S28	S33
S15	S15	S9	S14	S28	S33
S16	S16	S9	S14	S28	S33
S17	S17	S9	S14	S28	S33
S18	S18	S13	S16	S28	S35
S19	S19	S13	S16	S28	S35
S20	S20	S13	S16	S28	S35
S21	S21	S14	S16	S28	S33
S22	S22	S9	S14	S16	S33
S23	S23	S9	S14	S16	S33
S24	S24	S9	S14	S16	S33
S25	S25	S9	S14	S16	S33
S26	S26	S9	S14	S16	S33
S27	S27	S9	S14	S16	S33
S28	S28	S9	S14	S16	S33
S29	S29	S9	S14	S28	S33
S30	S30	S9	S14	S28	S33
S31	S31	S9	S14	S28	S33
S32	S32	S9	S14	S28	S33

Conclusions

This paper proposes the use of Flyod's algorithm for service restoration plan, since it has generalization capability and high processing speed. The large number of possible outage conditions and the need to provide a restoration plan in minimum time are argument in favor of this technique. The advantages are the final network configuration is independent of the initial status of the network switches, the solution procedure leads to the optimum or to a near optimum solution and avoid combinatorial explosion of the number of configurations to be tested. The above conclusions have been corroborated by the results displayed above. Thus it is believed that the use of Flyod's algorithm in power system restoration is option that should be considered and of continued search for real time application.

Conflict of interest

Authors declare there are no conflicts of interest.

References

[1] Mondon E, Heilbronn B, Harmand Y, Paillet O, Fargier H. MARS: An Aid for a Network Restoration after a Local Disturbance. IEEE transactions on power systems. 1992;7(2):850-855.

[2] Dialynas EN, Michos DG. Probabilistic Assessment of Service Restoration in Power Distribution Systems. IEEE Transactions on Power Delivery. 1991;6(4):1891-1898.

[3] Delfino B, Invernizzi M, Morini A. Knowledge Based Restoration Guidelines. IEEE Computer Applications in Power. 1992;5(3)54-59.

[4] Liu CC, Liou KL, Chu RF, Holen AT. Generation Capability Dispatch for Bulk Power System Restoration: A Knowledge-Based Approach. IEEE Transactions on Power Systems. 1993;8:316-325.

[5] Teo CY, Gooi HB. Restoration of Electrical Power Supply through an Algorithm and Knowledge based System. Electric Power Systems Research. 1994;29:171-180.

[6] Jiang W, Teo CY. A Knowledge-Based Approach for Bulk Power System Restoration. In International Conference on Energy Management and Power Delivery, IEEE Proceedings. 1995. pp. 108-111.

[7] Matsumoto K, Sakaguchi T, Kafka RJ, Adibi MM. Knowledge-Based Systems as Operational Aids in Power System Restoration. Proceedings of the IEEE. May 1992.

[8] Komai K, Matsumoto K, Sakaguchi T. Analysis and Evaluation of Expert's Knowledge for power system restoration by mathematical programming method. IEEE Conference Proceedings. 1988. pp. 1895-1898.

[9] Huang JA, Galiana FD, Vuong GT. Power system restoration incorporating interactive graphics and optimization. In Power Industry Computer Application Conference, IEEE Conference Proceedings. 1991. pp. 216-222.

[10] Morelato AL, Monticelli A. Heuristic Search Approach to Distribution System Restoration. IEEE Transactions on Power Delivery. 1989;4(4):2235-2241.

[11] Toune S, Fudo H, Genji T, Fukuyama Y, Nakanishi Y. Comparative Study of Modern Heuristic Algorithms to Service Restoration in Distribution Systems. IEEE transactions on Power Delivery. 2002;17:173-181.

[12] Sudhakar TD, Vadivoo NS, Slochanal SMR, Ravichandran S. Supply Restoration in Distribution Networks Using Flyod's Algorithm. IEEE Conference POWERCON, Singapore. 2004. pp. 641- 646.

[13] Sudhakar TD, Vadivoo NS, Slochanal SMR. Power Restoration Problem Analysis in various Distribution Systems. National Conference NPSC, IIT Madras, 2004. pp. 656 – 661.

[14] Leonhard E. Seven bridges Of Konigsberg, 1736.

[15] Zhu J, Chang. Refined genetic algorithm for minimum-loss reconfiguration of electrical distribution network. Proceedings of the International Conference on Energy Management and Power Delivery, 1998. pp 485-489.

[16] Shirmohammadi D, Hong HW. Reconfiguration of electric distribution networks for resistive line losses reduction. IEEE Transactions on Power Delivery. 1989;4(2)1492-1498.

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