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Research Article

Minimum Spanning Tree based Power Restoration in Distribution Network

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Abstract

The present paper deals with the restoration of the distribution following a partial blackout. The main issue during a restoration is to achieve the minimum deficit of power supply; a proper switching of power lines is required. Since time is a limiting factor and the decision making is a highly combinatorial problem, a graph theory based system is proposed in order to solve it. The restoration process can be decomposed into two main stages. The first one, power flow path identification, consists of switching status of all the K switches in order to energise a network. The second stage, load flow analysis, aims to supply the consumers effectively by satisfying the major constraints. The proposed methodology is tested on a 33 bus distribution network is tested to demonstrate the effectiveness of this study. The results obtained are comparable to the results available in the literature.

Keywords: Minimum Spanning Tree; Distribution network; Restoration; Switching; Graph theory.

Introduction

Each radial feeder is divided into several load sections with closed sectionalizing switches and has connections to other feeders via several open tie switches. The main purpose of the tie switches is to isolate or restore the loads during an outage or maintenance. For example, when an outage occurs on a bus, or on a transformer, or on one of the load sections of a feeder, all the load sections which are surrounded by the switch, including the outage point are, isolated from the system. As an outage occurs on the system, distribution system must be reconfigured as quickly as possible to restore as much out–of–service loads as possible.

Power restoration after an outage usually refers to an emergency situation and the resultant plan should meet the following requirements: It must restore as much load as possible while considering priority customers. It must not cause violations in either engineering or operating constraints. It must outline a feasible sequence of operations to reach the final configuration. Power balancing should be done. It must be reached in a short time. It must retain the radial network structure. This requirement is based on the feeder design for ease in fault location, isolation and protective device coordination. No components must be overloaded.

The implementation of power restoration in a vast distribution system is thus a complicated combinatorial optimization problem because there are a great number of switches in the distribution system. It may take a long time to reach a feasible restoration plan which satisfies all the aforementioned practical requirements if one tries to solve the problem using combinatorial optimization algorithms. Therefore, the dispatchers at many utilities tend to use their experience to narrow down and reach a proper restoration plan in a short period. This area has a received a lot of attention by the researchers in the past three decades as evidenced by the number of publications [1].

The automation of restoration of distribution power gained significance in the late eighties [2]. The state of the art methods used to solve the power system restoration for distribution system problems include Heuristic search [3], Expert system [4], and Knowledge based system [5]. Due to the advancement in mathematics new algorithms were developed to solve the restoration problem in distribution network. It mainly consisted of Artificial Neural Networks

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[6], Fuzzy Logic control [7], Genetic Algorithm [8], Artificial Intelligence [9], Petri net [10], Tabu search [11], Optimization [12], Ant colony search algorithm [13] and Particle Swarm Optimization [14].

The main drawback faced in using the above methods, was the difficulty in identifying all the distribution branches used for the power to flow, after an outage for which predefined rules were used. To overcome this drawback hybrid models were tried, for example fuzzy GA model [15]. To solve a complex combinatorial problem time required is more, so time required for solving restoration problem using any of the above said methods is high. Now if hybrid models are used then the time required to obtain a solution is too high. As a result it has become mandatory to identify the radial path of power flow with least mathematical efforts.

Most of the work reported focused on constraints like voltage limits, radiality and feeder capacity as the time required to obtain a restoration plan is more. To maintain these constraints load shedding is done immediately. Load shedding option would imply loss of supply to essential loads such as medical facilities. If the time consumed is less than the line losses and feeder capacity based on internal load division priority can be considered. To obtain the restoration plan quickly without any iterative procedure a graph theory based methodology using minimum spanning tree (MST) algorithms is proposed here.

Graph theory based on MST approach has been discussed in various papers with varied focuses. The authors [16], presents an algorithm for finding the shortest path for power routing (DC) between two nodes in an electrical network used in the airlines. The authors [17], present mathematically MST for network topological observability analysis. The authors [18], dealt with application of the MST is applied for finding the connectivity in the VLSI circuits. The authors [19], presented the minimization of energy losses in distribution systems by applying a general search method to a Brazil power network. Here outages were not been considered as an important factor to address. In paper [20], discusses about the application of Dijkstra’s algorithm for various applications like airline electrical networks which is the main advantage of the algorithm. The authors [21] indicate the use of Floyd – Warshall’s based MST to find the time scheduling in the data flow graph of a DSP. Author [22] uses the learning classifier system for loss minimization in a power system. The author [23] calculates the reliability index of radial network using forward search method of MST. The paper [24] discusses the depth first search method used to find the MST for the optimal placement of the PMU devices in the power system. Distribution reconfiguration algorithm, named Core Schema Genetic Shortest–path Algorithm (CSGSA) proposed in the paper [25], is based on the weights calculation method for each load condition based on line losses.

The above survey highlighted the extension of the application of graph theory for MV power distribution AC system, which has been attempted in this paper. Here, the mathematical formulation of Yixin Yu has been applied to a PDN wherein distribution branch outages have been fully addressed. Four algorithms based on graph theory are used to restructure the PDN by considering the distribution branch outage and this form the major contribution of this work.

The MST algorithm identifies all the possible paths for the power to flow and obtains only one solution; in a single iteration thereby overcoming the radiality constraint. Since, MST algorithm gives a path of minimum impedance; the line losses will be minimum with the result no separate loss minimization procedure is required here. The solution of MST algorithm is obtained in single iteration, as a result loss minimization and load shedding with internal priorities are included in the proposed work. Thus, in a minimum time a power system restoration solution is obtained, which will not lead to cascaded outage.

Problem formulation

In this section, the network reconfiguration problem for service restoration is discussed in detail. The system is represented on a per phase basis and the load along a feeder section is represented as constant P, Q loads placed at the end of the lines. It is assumed that every switch is associated with a line in the system. The network reconfiguration problem for loss reduction involves the load transfer between the feeders or substations by changing the position of the switches. The radial configuration corresponds to a 'spanning tree' of a graph representing the network topology.

Given a graph, find a spanning tree such that the, the problem formulation of the restoration problem is given here. Objective Function is to find the optimal power path, while the following constraints are satisfied:

(i) Power balance,
(ii) Voltage,
(iii) Radiality,
(iv) Line losses
(v) Feeder capacity and
(vi) Priority of customers.

This is a combinatorial optimization problem since the solution involves the consideration of all possible spanning trees.

Application of Proposed MST for Restoration of Power in Distribution Network

MST algorithm is a graph search algorithm that solves the single–source shortest path problem for a graph with non – negative weights, producing a shortest path tree. For a given source vertex (node) in the graph, the algorithm finds the path with lowest cost (i.e. the shortest path) between that vertex and every other vertex.

A single graph can have many different spanning trees. If an exhaustive search approach to construct a MST is tried, two serious obstacles arise. First, the number of spanning trees grows exponentially with the graph size and second, generating all spanning trees for a given graph is not easy. To overcome these drawbacks MST algorithms are proposed. They are as follows:

1. Reverse – Delete algorithm [26]
2. Dijkstra's algorithm [27]
3. Kruskal's algorithm [28]
4. Prim's algorithm [29]

In a radial distribution system to achieve a maximum amount of power restored, the aim is to identify the appropriate switching options, which consists of all the buses in the network. In the proposed method, the distribution system is considered with all its laterals simultaneously, instead of determining the switching options on loop by loop basis. In applying the graph theory the buses and the feeders are considered as the vertex, the distribution line are considered as edges and the impedance of the distribution line are considered as weight of the edge. With this consideration the proposed graph theory based algorithm for the distribution system is :

STEP 1. Initial power flow path is stored
STEP 2. Get the input data about the amount of loads at each bus, the feeder capacity and the current status of all the lines
STEP 3. In case of any outage remove those data from the input data file
STEP 4. Check for multi feeder or single feeder
STEP 5. If it is single feeder go for step 7
STEP 6. If it is multi feeder, then enter the number of feeders
STEP 7. Get the MST for the feeders
STEP 8. Perform the load flow for the resultant network
STEP 9. Check for multi feeder or single feeder
STEP 10. If it is single feeder go to step 13
STEP 11. Check for feeder overloading condition. If the feeders are overloaded, then load transferring can be done. If load transferring is not possible then perform load shedding. Otherwise if the feeders are not overloaded proceed to step 13.
STEP 12. Perform the load flow for the modified conditions
STEP 13. Check for over voltage condition. If the voltage limits are violated then perform load shedding otherwise proceed to step 15.
STEP 14. Perform the load flow for the modified conditions
STEP 15. Check for over current condition. If the current capacity are violated then perform load shedding otherwise proceed to step 17.
STEP 16. Perform the load flow for the modified conditions
STEP 17. If all the constraints are satisfied then display the optimal switching sequence

Results and discussions

The original configuration of 33 – bus test distribution network [28] has a total load capacity of 3.525 MW 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 + j 0.1240.

If an outage takes place in the line S16 i.e., between the buses 16 and 17, then the loads connected with the buses 17 to 18 will be isolated from the feeder 1, a partial blackout condition takes place here. To restore power to these isolated areas the proposed methodology is applied using the four different MST algorithms namely Prim's algorithm, Kruskal's algorithm, Dijkstra's algorithm and Reverse–Delete algorithm. Table 1 provides the switch that should be open so that the power is restored to the isolated area. The switches those act as tie switches, their total impedance and loss of the network after applying the respective algorithms are indicated in table 1.

Table 1. Switches that are open and the impedance of the network

Algorithm	Tie switches					Total impedance	Loss
Prim's	S16	S27	S33	S34	S35	$20.52 + j\,16.49$	$0.17 + j\,0.12$
Kruskal's	S16	S27	S33	S34	S35	$20.52 + j\,16.49$	$0.17 + j\,0.12$
Dijkstra's	S9	S14	S16	S28	S33	$26.15 + j\,2.46$	$0.16 + j\,0.11$
Reverse Delete	S16	S27	S33	S34	S35	$20.52 + j\,16.49$	$0.17 + j\,0.12$

Conclusions

A feeder reconfiguration method using MST for service restoration of radial distribution system is presented. From the important observations of the present study it could be concluded that: (i) The out–of–service area is reduced to the maximum by the developed MST methodology, (ii) The power losses of distribution systems are reduced by proper feeder reconfiguration, (iii) In addition to power–loss reduction, the voltage profile is improved by the proposed method and (iv) Based on the flowchart the feeder loads and load flow are performed each time, so that the effect of unbalanced power distribution network is also considered. Test results obtained indicate that, this method results in better restoration plan when compared to other reference papers.

Conflict of interest

Authors declare there are no conflicts of interest.

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