International Journal of Industrial Engineering, 2018;2(5):126-134.
ISSN: 2456-8449.
http://ijie.gjpublications.com

Research Article

Power System Restoration Based on Maximum Power Transfer using Dijkstra's Algorithm

T. D. Sudhakar, Udith Emmimal

Department of Electrical and Electronics, St. Joseph's College of Engineering,
Chennai - 600 119. India.

*Corresponding author's e-mail: sudhakar.t.d@gmail.com

Abstract

The present paper studies the service restoration of the distribution network based on real power flow of the distribution lines using Dijkstra's algorithm. The procedure is done to decrease the amount of load shedding and ensure quality of the voltage level under various outages and load conditions. The objective function in this paper is to maximize the amount of power restored with minimization of real power loss and the constraints of normal conditions of the distribution network. To crack this multi objective, multi constraint combinatorial problem, the methodology which is proposed has two steps. In step one Dijkstra's calculation is utilized to acquire the power flow path from the feeder to all the buses, which is based on maximum power transfer. Second step performs the load flow analysis. Based on the load flow analysis results the constraints are checked. The proposed methods are verified on 33-bus single feeder and 16-bus three feeder distribution network and the simulation results reveal their validity.

Keywords: Dijkstra's Algorithm; Distribution Network; Network Reconfiguration; Power System Restoration.

Introduction

Distribution network (DN) is a weekly meshed network, which are operated in a radial structure [1]. DN consists of sectional and tie switches. Network Reconfiguration (NR) is a process of changing the status of both the sectional and tie switches. The NR process is done during abnormal conditions like sudden load increase, outage of a line or outage of feeder. In all these conditions the supply of power to a portion or whole consumers are affected. So the power has to be restored to the isolated consumer by NR process. This complete process is known as Power System Restoration (PSR). The major task of PSR is to identify power flow path with satisfying all the constraints. The constraints are maximizing the amount of power restored; minimize the amount of losses, radiality, voltage limits, loading limits, feeder capacity and priority of the consumers [1]. Thus the PSR is a multi-objective, multi constraint combinatorial problem.

In the late eighties [2] the automation of the restoration problem in the distribution network has gained significance. The various approaches used for solving the power system restoration problems in distribution systems include Heuristic search [3], Expert system [4], and Knowledge based system [5]. New algorithms were developed due to the advancement in mathematics to solve the restoration problem in distribution network. It mainly consisted of Artificial Neural Networks [6], Fuzzy Logic control [7], Genetic Algorithm [8], Artificial Intelligence [9], Petri net [10], Tabu search [11], Optimization [12], Ant colony search algorithm [13], Particle Swarm Optimization [14].

The main drawback faced in using the above methods, was the difficulty in checking the radiality constraint, i.e., identifying all the distribution branches used for the power to flow, after an outage. For solving this constraint predefined rules were used. To overcome this drawback even hybrid models were tried, for example fuzzy GA model [15]. To solve a complex combinatorial problem time required are more, so time required for solving restoration problem using any of the above said methods is

Received: 21.05.2018; Received after Revision: 29.05.2018; Accepted: 29.05.2018; Published: 31.05.2018

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 minimizing the isolated area, voltage limits and feeder capacity. The important constraint of power distribution network is radiality, as the network is normally configured radially for the effective coordination of their protective systems. Line losses and feeder capacity based on internal load division priority were not considered as they were time-consuming. The internal priorities are used as the loads in each feeder loads are classified into very important persons loads, industrial loads, commercial loads and domestic loads; with daily variations in their load. Load shedding option would imply loss of supply to essential loads such as medical facilities. To overcome these drawbacks the graph theory based methodology using MST algorithm is proposed here.

The main aim is to restore as much load as possible, so in this paper a methodology based on Dijkstra's algorithm is proposed. The Dijkstra's algorithm a MST based 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, Dijkstra's algorithm gives a path of minimum power flow in a line; 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. In this methodology the load variation in the outage condition is also considered during the restoration process.

Problem Formulation

In this section, the service restoration problem is discussed in detail. The system is represented on a per phase basis and the loads are placed as constant P, Q loads at the end of the lines of a feeder. An assumption is done i.e., in a line of a system every switch is associated. The network reconfiguration problem for service restoration involves the changing of switch positions to transfer the loads between the feeders or substations. The radial configuration corresponds to a 'spanning tree' of a graph representing the network topology. The restoration problem formulation [16] is given here.

Objective is to find the Optimal Power Flow Path, while the following constraints are satisfied:

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

The restoration problem considers all the possible spanning trees; hence this problem is a combinatorial optimization problem.

Minimum Spanning Tree

A graph, [17] the basic subject studied by graph theory, is an abstract representation of a set of vertices also called as nodes or points. The lines or curves which join any two vertices will be the edge. A graph may be undirected, meaning that there is no distinction between the two vertices associated with edges; or it may be directed meaning that there is distinction from one vertex to another.

A spanning tree T of a connected, undirected graph G is a tree composed of all the vertices and some of the edges of G. In a MST no cycles (or loops) are formed. For a connected graph with V vertices, any spanning tree will have (V–1) edges. Assigning a weight to each edge, which is a number representing how unfavorable it is, a weight to a spanning tree can be assigned by computing the sum of the weights of the edges in that spanning tree. A minimum spanning tree (MST) or minimum weight of a spanning tree is then a spanning tree with weight less than or equal to the weight of every other spanning tree. This concept is often used in routing.

Application of the proposed Dijkstra's based methodology for restoration of power in distribution system

MST algorithm is a graph search algorithm to obtain a shortest path tree by solving a non – negative weight graph a shortest path tree is produced by obtaining the single-source shortest path. For a source vertex (node) in the graph, the algorithm finds the path with lowest cost between that vertex and every other vertex (i.e. the shortest path). For example, in the graph, if the graph vertices represent cities and edge path costs (weights) represent driving distances between pairs of cities connected by a direct road, these algorithms can be used to find the shortest route between one city and all other cities. 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.

The aim is to identify the appropriate switching options, in a radial distribution system to achieve a maximum amount of power restored. In maximum of the techniques, the losses are individually calculated by using load flow studies for each configuration, and the minimum loss configuration is found. In the proposed method, instead of determining the switching options on loop by loop basis, the distribution system is considered with all its laterals simultaneously. Most of the reported work involved very complex mathematical procedures and large computational time due to the combinatorial nature of the problem.

The proposed method obtains the switching option in a single iteration, thus minimizing the computational time of the restoration problem. In applying the graph theory the buses and the feeders are considered as the vertex, the distribution line are considered as edges and the real power of the end bus is considered as weight of the edge. With this consideration the proposed graph theory based algorithm for the distribution system is shown in figure 1.

Test cases and results

In a distribution network, the feeder is the supply point through which the power is supplied to the various load points. Based on the number of feeders available, the distribution network is classified as a single feeder distribution network or a multi feeder distribution network. In this section a single feeder 33–bus network and a multi feeder network namely a 16–bus three feeder network are considered.

33–bus single feeder network

The initial configuration of 33–bus single feeder distribution network [18] is shown in figure 2, which has a total load capacity of 3.525 MW and 2.3 MVAr. The 33–bus test system consists of one source feeder and 32 load points. The network consists of 33 buses and 37 branches, where branches S1–S32 and S33–S37 indicate the sectional and tie line switches respectively. The line data of the network is shown in table 1. The total impedance of the network for the initial configuration having sectional lines is 28.4210 Ω and the real and reactive power losses of the network are 0.1869 MW and 0.1240 MVAr respectively. The minimum p.u. voltage of 0.9122 p.u. is at bus number 18. The system base voltage is 12.66 kV and the VA capacity is 10 MVA.

The proposed methodology using Dijkstra's algorithm [18] is applied to the 33–bus network for normal conditions and the results are tabulated in table 2. For the same network Hybrid GA [19] and Heuristic Search method [20] has been applied. Their results are tabulated in Table 2. From table 2 it is observed that the losses are less and the minimum p.u. voltage of the buses is higher by Dijkstra's algorithm compared to the other values obtained (Table 2). The real and reactive power losses of the network are 0.1869 MW and 0.1240 MVAr respectively. The minimum p.u. voltage of 0.9122 p.u. is at bus number 18. The system base voltage is 12.66 kV and the VA capacity is 10 MVA.

Using the proposed methodology incorporating Dijsktra's algorithm for a single line outage condition, in 33–bus distribution network the tie switches are obtained and tabulated in table 3. In the proposed methodology the effect of loads are also considered. For example if the load at the bus 24 is doubled during the normal conditions then the tie switches are S7, S9, S14, S24 and S31.

The proposed methodology is applied for outages at two lines simultaneously to the 33–bus distribution network. For example if the outage takes place in the switches S10 & S16 load connected between the bus 11 & bus 18 get isolated. To restore the power to these isolated areas, the switching sequence is to be identified using the proposed methodology and they are S10, S14, S16, S28 and S33. In a similar manner using the proposed methodology the switching sequence is obtained for any number of outages at the same time.

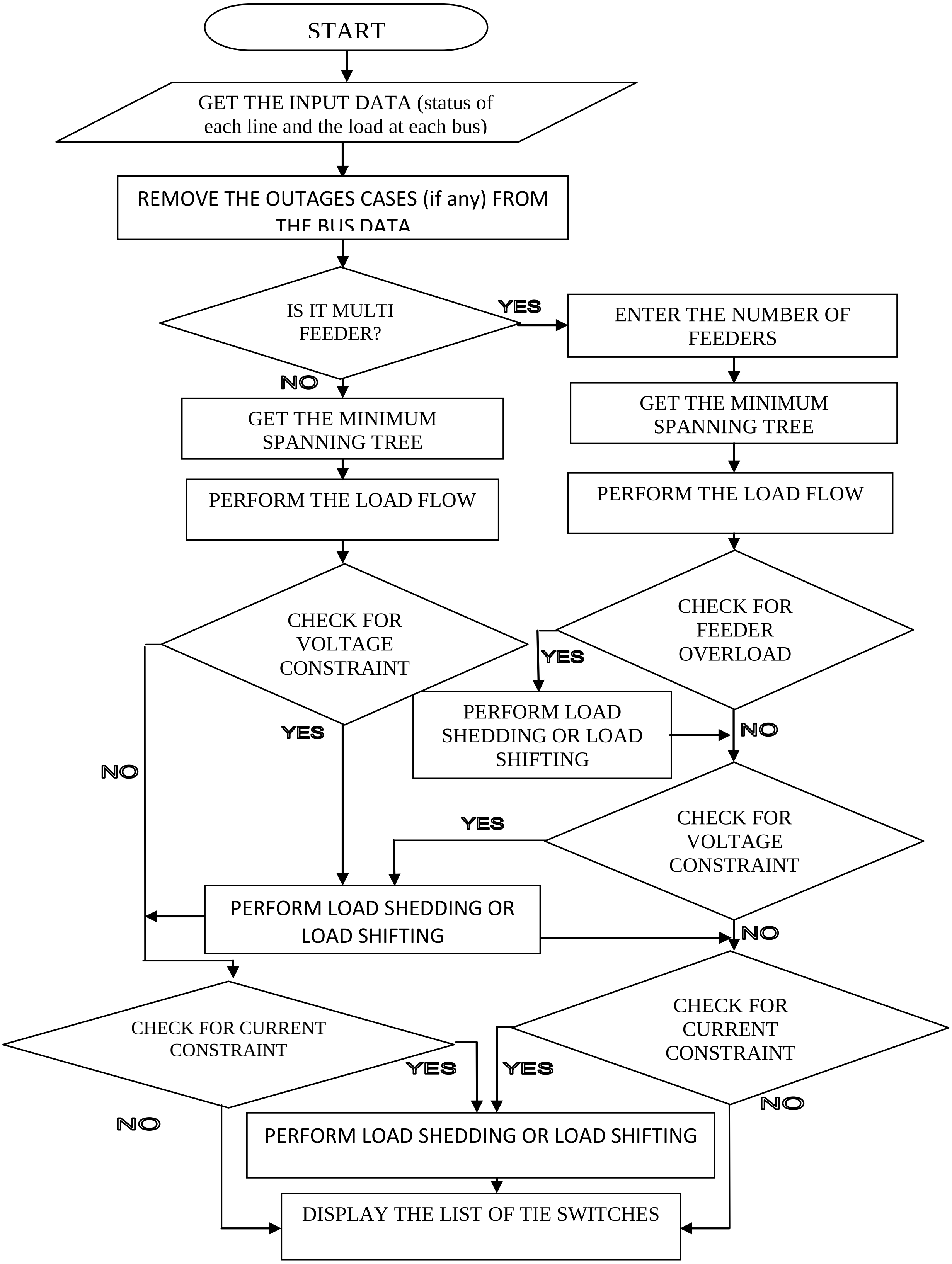

Figure 1. Flowchart of the restoration problem for finding the power flow path

IEEE 16–bus three feeder network

Consider the IEEE 16–bus system [19] as shown in Figure 3 and the details of the network is given in Table 4. A radial network with 16 buses, 13 sectional lines and 3 tie lines are selected. Bus 1 (feeder), bus 2 (feeder) and bus 3 (feeder) act as a root node and the other buses (loads) act as end nodes.

The initial tie lines of the network are S5, S11 and S16. The total impedance of the network is 1.7460 Ω. The minimum p.u. voltage is 0.9682 at the bus number 12 and the total real power loss is 0.72 MW. After applying the

Dijkstra's algorithm the tie lines are S5, S11 and S16. For the same network multicost multi point alternative supply and loss change estimation method have been applied [21-26]. Their results are tabulated in table 5, along with the results of Dijkstra's algorithm.

Table 1. Line data of 33 – bus single feeder distribution network

Switch	SB	EB	R (Ω)	X (Ω)	Z (Ω)	P(KW)	Q(KVAr)
S1	1	2	0.0922	0.0477	0.1038	100	60
S2	2	3	0.4930	0.2511	0.5533	90	40
S3	3	4	0.3660	0.1840	0.4096	120	80
S4	4	5	0.3811	0.1941	0.4277	60	30
S5	5	6	0.8190	0.0700	0.8220	60	20
S6	6	7	0.1872	0.6188	0.6465	200	100
S7	7	8	1.7114	1.2351	2.1105	200	100
S8	8	9	1.0300	0.7400	1.2683	60	20
S9	9	10	1.0400	0.7400	1.2764	60	20
S10	10	11	0.1966	0.0650	0.2071	45	30
S11	11	12	0.3744	0.1238	0.3943	60	35
S12	12	13	1.4680	1.1550	1.8679	60	35
S13	13	14	0.5416	0.7129	0.8953	120	80
S14	14	15	0.5910	0.5260	0.7912	30	10
S15	15	16	0.7463	0.5450	0.9241	30	20
S16	16	17	1.2890	1.7210	2.1502	30	20
S17	17	18	0.7320	0.5740	0.9302	90	40
S18	2	19	0.1640	0.1565	0.2267	90	40
S19	19	20	1.5042	1.3554	2.0248	90	40
S20	20	21	0.4095	0.4784	0.6297	90	40
S21	21	22	0.7089	0.9373	1.1752	90	40
S22	3	23	0.4512	0.3083	0.5465	90	50
S23	23	24	0.8980	0.7091	1.1442	420	200
S24	24	25	0.8960	0.7011	1.1377	420	200
S25	6	26	0.2030	0.1034	0.2278	60	25
S26	26	27	0.2842	0.1447	0.3189	60	25
S27	27	28	1.0590	0.9337	1.4118	60	20
S28	28	29	0.8042	0.7006	1.0666	20	70
S29	29	30	0.5075	0.2585	0.5695	200	600
S30	30	31	0.9744	0.9630	1.3700	150	70
S31	31	32	0.3105	0.3619	0.4768	210	100
S32	32	33	0.6410	0.5302	0.8319	60	40
S33	21	8	2.0000	2.0000	2.8284		
S34	9	15	2.0000	2.0000	2.8284		
S35	12	22	2.0000	2.0000	2.8284		
S36	18	33	0.5000	0.5000	0.7071		
S37	25	29	0.5000	0.5000	0.7071		

Table 2. Switches that are open and their parameters of the network using the proposed methodology

Algorithms	Tie Switches					Total Impedance	Real power loss	Reactive power loss	Minimum p.u. Voltage	Bus No of Min p.u. Voltage
						Ω	MW	Mvar	p.u.	
Normal	S33	S34	S35	S36	S37	28.4210	0.1869	0.1240	0.912	18
Dijkstra's	S7	S9	S14	S31	S37	31.0914	0.1254	0.9090	0.934	32
Refined GA	S7	S10	S14	S36	S37	33.7917	0.2007	0.1776	0.883	33
Heuristic Method	S7	S9	S14	S32	S37	32.5863	0.1984	0.1760	0.887	32

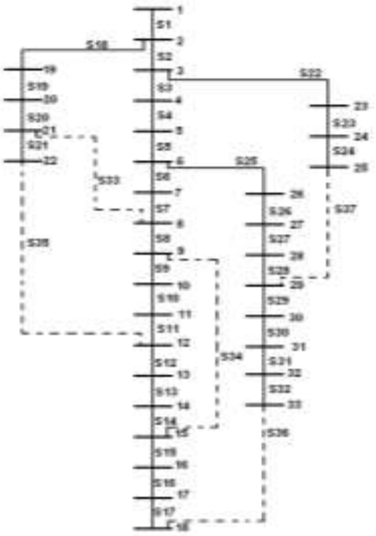

Figure 2. 33–bus single feeder distribution network

Table 5 gives the list of switches that are open during normal conditions. In power system, outage in a line can take place; during such conditions the proposed methodology can be used. Table 6 gives the list of switches that are open for the single line outage cases using Dijkstra's algorithm with their feeder capacity. Table 7 gives the list of switches that must be open using the proposed methodology for the double line outages condition. In the table the diagonal elements are empty as it indicates the single line outage condition.

Table 3. Result for single line outage in 33–bus network

OUTAGE on LINE	TIE SWITCHES				
S1	Power system cannot be restored				
S2	S2	S9	S14	S31	S37
S3	S3	S9	S14	S31	S37
S4	S4	S9	S14	S31	S37
S5	S5	S9	S14	S31	S37
S6	S6	S9	S14	S31	S37
S7	S7	S9	S14	S31	S37
S8	S8	S7	S14	S31	S37
S9	S9	S7	S14	S31	S37
S10	S10	S7	S14	S31	S37
S11	S11	S7	S14	S31	S37
S12	S12	S7	S9	S31	S37
S13	S13	S7	S9	S31	S37
S14	S14	S7	S9	S31	S37
S15	S15	S7	S9	S14	S37
S16	S16	S7	S9	S14	S37
S17	S17	S7	S9	S14	S37
S18	S18	S9	S14	S31	S37
S19	S19	S9	S14	S31	S37
S20	S20	S9	S14	S31	S37
S21	S21	S7	S14	S31	S37
S22	S22	S7	S9	S14	S31
S23	S23	S7	S9	S14	S31
S24	S24	S7	S9	S14	S31
S25	S25	S7	S9	S14	S37
S26	S26	S7	S9	S14	S37
S27	S27	S7	S9	S14	S37
S28	S28	S7	S9	S14	S37
S29	S29	S7	S9	S14	S37
S30	S30	S7	S9	S14	S37
S31	S31	S7	S9	S14	S37
S32	S32	S7	S9	S14	S37

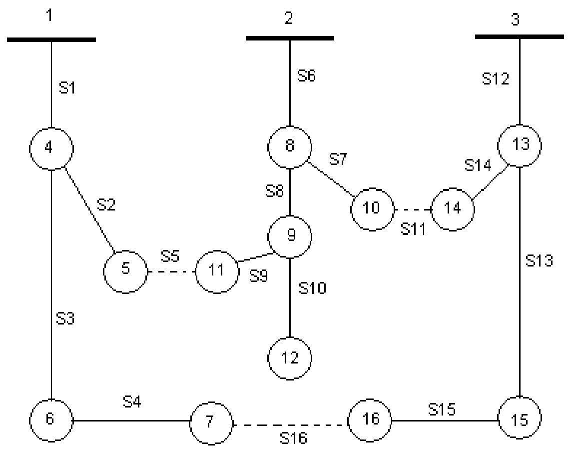

Figure 3. 16–bus three feeder distribution network

Table 4. Line data of 16–bus three feeder distribution network

Switch	SB	EB	R (Ω)	X (Ω)	Z (Ω)	P (MW)	Q (MVAr)
S1	1	4	0.075	0.10	0.1250	2.0	1.5
S2	4	5	0.080	0.11	0.1360	3.0	1.5
S3	4	6	0.090	0.18	0.2012	2.0	0.8
S4	6	7	0.04	0.04	0.0566	1.5	1.2
S6	2	8	0.11	0.11	0.1556	4.0	2.7
S7	8	9	0.08	0.11	0.1360	5.0	3.0
S8	8	10	0.11	0.11	0.1556	1.0	0.9
S9	9	11	0.11	0.11	0.1556	0.6	0.1
S10	9	12	0.08	0.11	0.1360	4.5	2.0
S12	3	13	0.11	0.11	0.1556	1.0	0.9
S13	13	14	0.09	0.12	0.1500	1.0	0.7
S14	13	15	0.08	0.11	0.1360	1.0	0.9
S15	15	16	0.04	0.04	0.0566	2.1	1.0
S5	5	11	0.04	0.04	0.0566		
S11	10	14	0.04	0.04	0.0566		
S16	7	16	0.09	0.12	0.1500		

Table 5. Switches that are open and their parameters of the network using the proposed methodology and reference papers

Algorithm	Tie Switches			Total Impedance (Ω)	Real power loss (MW)	Minimum p.u. Voltage (p.u.)	Bus No of Min p.u. Voltage
NORMAL	S5	S11	S16	1.7460	1.21	0.96836	12
Dijkstra's	S5	S11	S16	1.7460	1.21	0.96836	12
Multicost multi point alternative supply	S3	S7	S9	1.5044	This switching sequence cannot be applied as feeder 3 violates the capacity constraint		
Loss change estimation method	S4	S7	S9	1.6617	This switching sequence cannot be applied as feeder 3 violates the capacity constraint		

Table 6. Results for outages at single line using proposed methodology

O/L*	Tie Lines			Feeder Capacity						% Feeder Capacity					
				PI	QI	PII	QII	PIII	QIII	PI	QI	PII	QII	PIII	QIII
S1	S1	S3	S11	0	0	20.1	11.7	8.6	5.5	0	0	133	134	169	157
S1	S1	S4	S11	0	0	22.1	12.5	6.6	4.7	0	0	146	144	129	134
S2	S2	S11	S16	5.5	3.5	18.1	10.2	5.1	3.5	64.7	70	120	117	100	100
S3	S3	S9	S11	5.6	3.1	14.5	8.6	8.6	5.5	65.9	62	96	99	169	157
S4	S4	S9	S11	7.6	3.9	14.5	8.6	6.6	4.7	89.4	78	96	99	129	134
S6	S6	S3	S8	15	8.1	0	0	14	9.1	178	162	0	0	267	260
S6	S6	S3	S8	13	6.6	0	0	7.4	5	148	132	0	0	144	143
	50 % load shed at bus 9							50 % load shed at bus 6,7,8,14,15,16							
S7	S7	S5	S16	8.5	5	14.1	7.8	6.1	4.4	100	100	93	90	120	126
S8	S8	S11	S16	19	10.1	5	3.6	5.1	3.5	219	202	33	41	100	100
S8	S8	S11	S4	12	6.4	5	3.6	6.6	4.7	145	128	33	41	129	134
						50 % load shed at bus 9 & 12									
S9	S9	S11	S16	9.1	5.1	14.5	8.6	5.1	3.5	107	102	96	99	100	100
S10	S10	S5	S11 S16	8.5	5	10.6	6.7	5.1	3.5	100	100	70	77	100	100
S12	S12	S9	S15	11	6.1	17.5	11.1	0	0	132	122	116	128	0	0
S13	S13	S5	S11	12	6.9	15.1	8.7	2	1.6	136	138	100	100	39.2	45.7
S14	S14	S4	S9	7.6	3.9	15.5	9.3	5.6	4	89.4	78	103	107	110	114
S15	S15	S11	S15	11	6	15.1	8.7	3	2.5	125	120	100	100	58.8	71.4

*Where O/L indicates OUTAGE AT LINE

Table 7. Results for outages at two lines simultaneously using proposed methodology

O/L	S1	S2	S3	S4	S6	S7	S8	S9	S10	S12	S13	S14	S15
S1	-	S11	S11	S11	S2	S3	S11	S11	S11	S4	S11	S2	S11
S2	S11	-	S11	S11	S15	S15	S11, S16	S11, S16	S11, S16	S14	S11	S16	S11
S3	S11	S11	-	S9, S11	S7	S9	S11	S11	S9, S11	S9	S9, S11	S9	S9, S11
S4	S11	S11	S9, S11	-	S11	S9	S11	S11	S9, S11	S9	S9, S11	S9	S9, S11
S6	S2	S15	S7	S11	-	S16	S16	S16	S9, S16	S11	S9	S16	S9
S7	S3	S15	S9	S9	S16	-	S16	S16	S5, S16	S5, S16	S5, S16	S5, S16	S9, S16
S8	S11	S11, S16	S11	S11	S16	S16	-	S14, S16	S14, S16	S13	S4	S16	S14
S9	S11	S11, S16	S11	S11	S16	S16	S14 S16	-	S11, S16	S13	S11	S16	S11
S10	S11	S11, S16	S9, S11	S9, S11	S9, S16	S5, S16	S14, S16	S11, S16	-	S5, S13	S9, S11	S9, S16	S5, S11
S12	S4	S14	S9	S9	S11	S5, S16	S13	S13	S5, S13	-	S9	S9	S9
S13	S11	S11	S9, S11	S9, S11	S9	S5, S16	S4	S11	S9, S11	S9	-	S9	S9, S11
S14	S2	S16	S9	S9	S16	S5, S16	S16	S16	S9, S16	S9	S9	-	S9
S15	S11	S11	S9, S11	S9, S11	S9	S9, S16	S14	S11	S5, S11	S9	S9, S11	S9	-

where O/L is the outage on line

Conclusions

A methodology of obtaining the switching sequence using MST based algorithm during normal and abnormal conditions like outages is proposed in this paper. The proposed methodology has two stages. The first stage uses MST based Dijkstra's algorithm to find the power flow path. This power flow path identification is based on real power flow of the distribution lines. The second stage is load flow analysis. Using the results of load flow analysis other constraints are checked. It is also capable of giving a solution for variable load conditions; hence this method can be used for restoration of power in large distribution networks.

Conflicts of interest

Authors declare no conflict of interest.

References

[1] Sudhakar TD. Power Restoration in Distribution Network Using MST Algorithms. In Book: New Frontiers in Graph Theory. Zhang Y (Eds.). IntechOpen, 2012. pp. 285-306.

[2] Adibi MM, Kafka RJ. Power System Restoration Issues. IEEE Computer Applications in Power. 1991;4:19-24.

[3] Morelato AL, Monticelli A. Heuristic Search Approach to Distribution System Restoration. IEEE Transactions on Power Delivery. 1989;4:2235-41.

[4] Hotta K, Nomura H, Takemoto H, Suzuki K, Nakamura S, Fukui S. The Implementation of a Real-Time Expert System for a Restoration Guide in a Dispatching Center. IEEE Transactions on Power Systems. 1990;5:1032-38.

[5] Matsumoto K, Sakaguchi T, Kafka RJ, Adibi MM. Knowledge-Based Systems as Operational Aids in Power System Restoration. Proceedings of the IEEE. 1992l;80:689-97.

[6] Hoyong Kim H, Ko Y, Jung KH. Artificial Neural-Network based Feeder Reconfiguration for Loss Reduction in Distribution Systems. IEEE Transactions on Power Systems. 1993;8:1356-66.

[7] Kuo HC, Hsu YY. Distribution System Load Estimation and Service Restoration using a Fuzzy Set Approach. IEEE

Transactions on Power Delivery. 1993;8:1950-57.
[8] Levitin G, Tov SM, Elmakis D. Genetic algorithm for optimal sectionalizing in radial distribution systems with alternative supply. Electric Power Systems Research. 1995;35:149-55.
[9] Rahman S. Artificial intelligence in electric power systems – a survey of the Japanese industry. IEEE Transactions on Power System. 1993;8:1211-18.
[10] Fountas NA, Hatziargyriou ND, Valavanisl KP. Hierarchical Time Extended Petri Nets As A Generic Tool For Power System restoration. IEEE Transactions on Power Systems. 1997;12:837-43.
[11] Toune S, Fudo H, Genji T, Fukuyama Y, Nakanishi Y. A reactive tabu search for service restoration in electric power distribution systems. In IEEE International Conference on Evolutionary Computation Proceedings. 1998. pp. 763-768.
[12] Nagata T, Sasaki H., A Multi-Agent Approach to Power System Restoration. IEEE Transactions on Power Systems. 2002;17:457-62.
[13] Mohanty I, Kalita J, Das S, Pahwa A, Buehler E. Ant algorithms for the optimal restoration of distribution feeders during cold load pickup. Proceedings of the Swarm Intelligence Symposium. 2003. pp. 132-37.
[14] Sheng SQ, Cao Y, Yao Y. Distribution Network Reconfiguration Based on Particle Swarm Optimization and Chaos Searching. Asia-Pacific Power and Energy Engineering Conference. 2009. pp. 1-4.
[15] Hsiao YT, Chien CY. Enhancement of Restoration Service in Distribution Systems Using a Combination Fuzzy – GA Method. IEEE Transactions on Power Systems. 2000;15:1394-1400.
[16] Sudhakar TD, Srinivas KN. Restoration of power network–a bibliographic survey. International Transactions on Electrical Energy Systems. 2011;21(1):635-55.
[17] Mohanram S, Sudhakar TD. Power System Restoration using Reverse Delete Algorithm Implemented in FPGA. National Conference on Emerging Trends in Micro / Nano Electronics Engineering. 2011. pp. 326-31.
[18] Sudhakar TD, Srinivas KN. A Graph Theory-based Distribution Feeder Re-Configuration for Service Restoration. International Journal of Power and Energy Systems. 2011;30(3):161-68.
[19] Zhu J, Chang CS. Refined Genetic Algorithm for Minimum–Loss Reconfiguration of Electrical Distribution Network. Proceedings of International Conference on Energy Management and Power Delivery. 1998;2:485-89.
[20] Shirmohammadi D, Hong W. Reconfiguration of Electric Distribution Networks for Resistive Line Lossless Reduction. IEEE Transactions on Power Delivery. 1989;4:1492-98.
[21] Alberto V, Omar F. Optimal radialization of primary distribution networks with multicost and multipoint alternative supply. 14th PSCC Power Systems Computation Conference, Sevilla; España. 2002, pp. 1-7,
[22] Castro Jr CA, Watanabe AA. An efficient reconfiguration algorithm for loss reduction of distribution systems. Electric Power Systems Research. 1990;19:137-44.
[23] Ibrahim MMR, Mostafa HA, Salama MA, El-Shatshat R, Shaban KB. A graph-theoretic service restoration algorithm for power distribution systems. Proceedings of the International Conference on Innovative Trends in Computer Engineering. Aswan, Egypt; 19-21 Feb. 2018.
[24] Neagu RC, Georgescu G. Wind farm cable route optimization using a simple approach. Proceedings of the International Conference and Exposition on Electrical and Power Engineering, Iasi; Romania. 16-18 Oct. 2014.
[25] Jiang Z, Xiao F, Ai Q, He Q, Sun Q. Two-phase integrated optimisation strategy for network restoration with photovoltaic generation. The Journal of Engineering. 2017;2017:1076–81.
[26] Balakrishna P, RajagopalK, Swarup KS. Adaptive feeder load management and control during distribution power restoration based on DA and AMI systems integration approach. Sustainable Energy, Grids and Networks. 2016;6:136-42.

****

