

# Simulation of Blackout Recovery in Transmission Side Using N-R Method

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**Abstract**—A graph theory based methodology called Dijkstra’s algorithm is used to find the energizing path of power to flow for a given network after a complete blackout is proposed here. Whenever a blackout occurs in the transmission network, the power system operators are under immense pressure to restore the network. The main aim of the power system restoration is to restore as much load as possible and as quickly as possible. After a blackout occurs first all the generators has to be energized and then synchronized. After synchronization of generators only all the loads can be supplied. For energizing the generators a sequential procedure has to be followed. If the sequence used is wrong then it may lead to cascaded outages. The Dijkstra’s algorithm helps in finding the sequence to energize the generators based on least impedance path called minimum spanning tree. Newton Raphson based load flow technique is applied to this resultant minimum spanning tree (power flow path). Based on the results (voltage, current and power flow) obtained from the load flow solutions, other constraints of the restoration problem are applied.

**Index Terms**—graph theory, blackout, minimum spanning tree, load flow solution

## I. INTRODUCTION

Power system is a complex network involving the flow of power, which is generated using various techniques to meet the need of the industries or domestic consumers [1]. A brownout is an intentional drop in voltage in an electrical power supply system used for load reduction in an emergency. A voltage reduction may be an effect of disruption of an electrical grid, or may occasionally be imposed in an effort to reduce load and prevent a blackout [2].

## II. LOAD FLOW ANALYSIS

Power flow studies are of great importance in planning & designing the future expansion of power system as well as in determining the best operation of existing systems. The principle information obtained from power flow study is the magnitude and phase angle of voltage at each bus the real and reactive power following in each line [3]. Power flow calculations usually employ iterative techniques such as Newton-Raphson method solves the

polar form of power flow equations until  $\Delta P$  and  $\Delta Q$  mismatches at all buses fall within specified tolerances [4]. Newton’s method is a successive approximation procedure based on initial estimate of the unknown and the use of Taylor’s series expansion and the terms are limited to first order approximation. LF Newton is developed for solution of power flow problems by Newton Raphson method.

## III. GRAPH THEORY

Graph theory is a branch of data structures concerned about how the networks can be encoded and their properties measured. A graph (G) is a set of points called vertices and the lines connecting the points called Edges. The graphs are broadly classified into two types. 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. Here electrical network is analyzed as an undirected and weighted graph.

## IV. DIJKSTRA’S ALGORITHM

Dijkstra’s algorithm, conceived by Dutch computer scientist Edsger Dijkstra in 1959, is a graph search algorithm that solves the single-source shortest path problem for a graph with nonnegative edge path costs, producing a shortest path tree [5]. It can also be used for finding costs of shortest paths from a single vertex to a single destination vertex by stopping the algorithm once the shortest path to the destination vertex has been determined. Fig. 1 shows the example problem to find the minimum spanning tree.

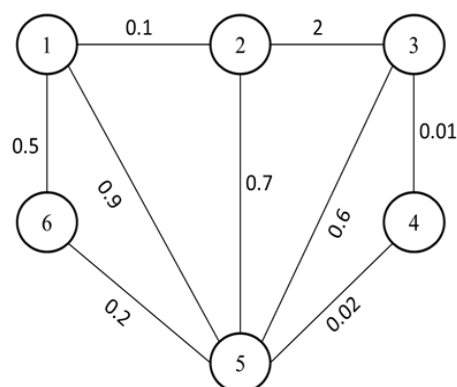


Figure 1. Example problem

By applying Dijkstra’s Algorithm we get minimum spanning tree of distance 0.83. Fig. 2 shows the minimum spanning tree found by using Dijkstra’s algorithm. Table I, shows the comparison of results of various algorithm in finding the minimum spanning tree when considering Fig. 1 as example.

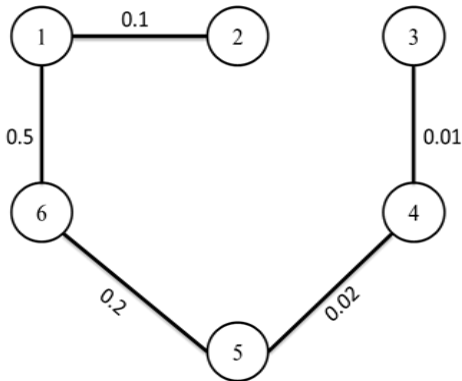


Figure 2. Minimum spanning tree by Dijkstra’s algorithm

TABLE I. COMPARISON OF RESULTS OF VARIOUS ALGORITHMS

Algorithm	Distance Calculated from Minimum Spanning Tree
Prim’s Algorithm	1.03
Dijkstra’s Algorithm	0.83
Kruskal’s Algorithm	1.03
Reverse Delete Algorithm	1.03

V. RECOVERY PROCESS

The whole recovery process is divided into 3 stages.

A. Black Start

Due to any critical fault or transient in the network a complete blackout will be occurring [6]. Fig. 3 shows the initial network for which we apply Dijkstra’s algorithm to find the minimum spanning tree. Table II, shows the bus data of initial network. Table III, shows the output of initial network found by using Newton Raphson Method. Table IV, shows the detailed output of initial network including the total line losses.

B. System Reconstruction

The generator (Slack bus) started first and based on the sequence of starting and starting time the generators on the network are started [7]. Fig. 4 shows the system Reconstruction stage where all the generators are excited from slack bus (here Bus 31).

C. Load Recovery

Initially the critical loads are fed and later after stabilization of the critical loads all other loads are connected [8]. Fig. 5 shows the load Recovery stage where all the loads are restored. Section VI, shows the results of Newton Raphson method. It gives the detailed output.

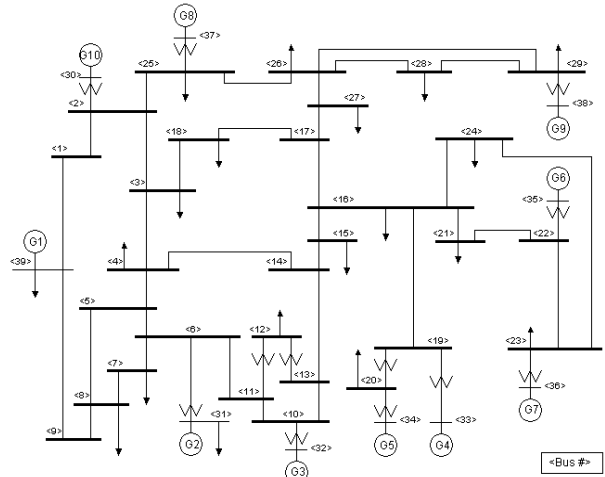


Figure 3. Initial network

TABLE II. BUS DATA OF INITIAL NETWORK

Bus No	Bus Code	Voltage	Load		Generator	
			MW	Mvar	MW	Mvar
1	0	1	0	0	0	0
2	0	1	0	0	0	0
3	0	1	322	2.4	0	0
4	0	1	500	184	0	0
5	0	1	0	0	0	0
6	0	1	0	0	0	0
7	0	1	233.8	84	0	0
8	0	1	522	176	0	0
9	0	1	0	0	0	0
10	0	1	0	0	0	0
11	0	1	0	0	0	0
12	0	1	7.5	88	0	0
13	0	1	0	0	0	0
14	0	1	0	0	0	0
15	0	1	320	153	0	0
16	0	1	329	32.3	0	0
17	0	1	0	0	0	0
18	0	1	158	30	0	0
19	0	1	0	0	0	0
20	0	1	628	103	0	0
21	0	1	274	115	0	0
22	0	1	0	0	0	0
23	0	1	247.5	84.6	0	0
24	0	1	308.6	-92	0	0
25	0	1	224	47.2	0	0
26	0	1	139	17	0	0
27	0	1	281	75.5	0	0
28	0	1	206	27.6	0	0
29	0	1	283.5	26.9	0	0
30	2	1	0	0	250	0
31	1	1	9.2	4.6	0	0
32	2	1	0	0	650	0
33	2	1	0	0	632	0
34	2	1	0	0	508	0
35	2	1	0	0	650	0
36	2	1	0	0	560	0
37	2	1	0	0	540	0
38	2	1	0	0	830	0
39	2	1	1104	250	1000	0

TABLE III. OUTPUT OF INITIAL NETWORK

Load		Generation		Injected
MW	Mvar	MW	Mvar	Mvar
6097	1409	6145	1445.9	0

TABLE IV. DETAILED OUTPUT OF INITIAL NETWORK

Total Line loss	
MW	Mvar
48.310	36.862

Bus no	Voltage	Angle	Load		Generation		Injected
			MW	Mvar	MW	Mvar	Mvar
1	1.004	-8.408	0	0	0	0	0
2	0.985	-5.3	0	0	0	0	0
3	0.966	-8.525	322	2.4	0	0	0
4	0.944	-9.657	500	184	0	0	0
5	0.95	-8.525	0	0	0	0	0
6	0.953	-7.782	0	0	0	0	0
7	0.942	-10.22	233	84	0	0	0
8	0.942	-10.77	522	176	0	0	0
9	0.988	-10.47	0	0	0	0	0
10	0.962	-4.966	0	0	0	0	0
11	0.958	-5.922	0	0	0	0	0
12	0.937	-5.876	7.5	88	0	0	0
13	0.957	-5.712	0	0	0	0	0
14	0.951	-7.457	0	0	0	0	0
15	0.947	-7.538	320	153	0	0	0
16	0.961	-7.538	329	32.3	0	0	0
17	0.965	-5.752	0	0	0	0	0
18	0.964	-8.098	158	30	0	0	0
19	0.979	0.195	0	0	0	0	0
20	0.976	-0.81	628	103	0	0	0
21	0.959	-2.97	274	115	0	0	0
22	0.976	2.178	0	0	0	0	0
23	0.973	1.939	247	84.6	0	0	0
24	0.967	-5.612	308	-92	0	0	0
25	0.996	-3.796	224	47.2	0	0	0
26	0.987	-5.072	139	17	0	0	0
27	0.97	-7.291	281	75.5	0	0	0
28	0.989	-1.128	206	27.6	0	0	0
29	0.992	1.96	283	26.9	0	0	0
30	1	-2.668	0	0	250	87.2	0
31	1	0	9.2	4.6	525	227.	0
32	1	2.801	0	0	650	234.	0
33	1	5.394	0	0	632	141.	0
34	1	4.497	0	0	508	133	0
35	1	7.64	0	0	650	195	0
36	1	10.907	0	0	560	133	0
37	1	3.416	0	0	540	336	0
38	1	9.433	0	0	830	65.8	0
39	1	-10.19	110	250	100	190	0

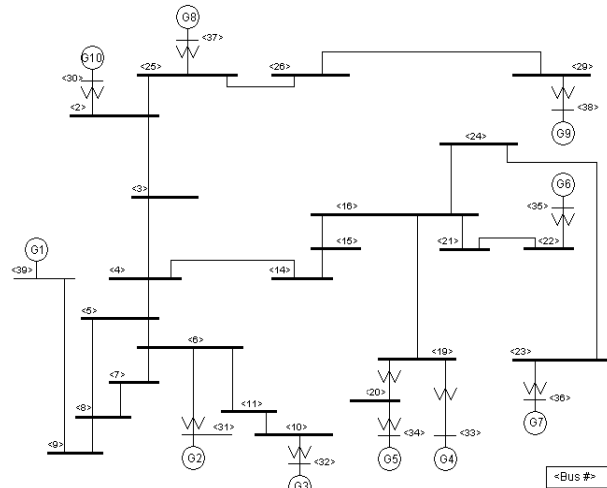


Figure 4. System reconstruction stage

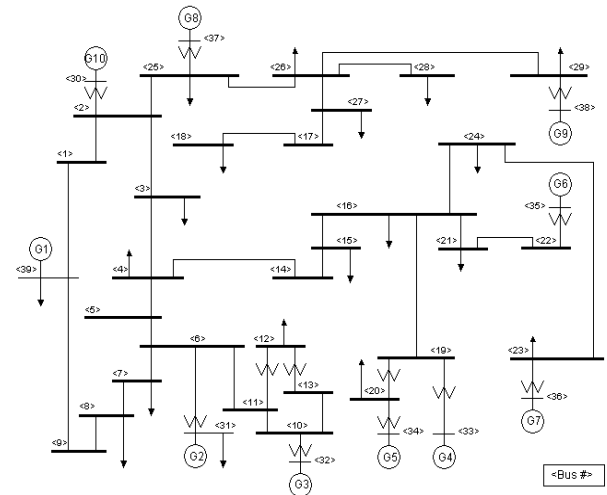


Figure 5. Load recovery stage

VI. RESULTS OF NEWTON-RAPHSON METHOD

--Line-- From to	Power at bus & line flow			--Line loss--	
	MW	Mvar	MVA	MW	Mvar
1	0.000	0.000	0.000		
2	-125.392	24.820	127.824	0.671	-61.246
39	125.392	-24.820	127.824	0.158	-71.359
2	0.000	0.000	0.000		
1	126.063	-86.066	152.640	0.671	-61.246
3	363.659	94.209	375.664	1.924	-2.131
25	-239.722	66.443	248.759	4.534	-8.760
30	-250.000	-74.586	260.889	0.000	12.691
3		-322.000	-2.400	322.009	
2	-361.736	-96.340	374.345	1.924	-2.131
4	90.339	85.188	124.170	0.241	-16.229
18	-50.603	8.752	51.355	0.034	-19.479
4		-500.000	-184.000	532.781	
3	-90.098	-101.416	135.657	0.241	-16.229
5	-140.702	-43.228	147.193	0.190	-8.983
14	-269.200	-39.356	272.062	0.661	-1.741
5	0.000	0.000	0.000		
4	140.892	34.245	144.995	0.190	-8.983
6	-457.407	-77.875	463.988	0.476	2.265
8	316.514	43.629	319.507	0.911	-0.462
6	0.000	0.000	0.000		
5	457.883	80.139	464.843	0.476	2.265
7	420.738	84.670	429.173	1.223	8.594
11	-362.412	-21.029	363.021	1.014	-0.800

31	-516.210	-143.780	535.859	0.000	79.029
7		-233.800	-84.000	248.432	
6	-419.516	-76.076	426.358	1.223	8.594
8	185.716	-7.924	185.885	0.155	-5.140
8		-522.000	-176.000	550.872	
5	-315.604	-44.092	318.669	0.911	-0.462
7	-185.560	2.784	185.581	0.155	-5.140
9	-20.836	-134.692	136.294	0.371	-29.592
9	0.000	0.000	0.000		
8	21.207	105.100	107.218	0.371	-29.592
39	-21.207	-105.100	107.218	0.027	-117.899
10	0.000	0.000	0.000		
11	364.020	65.127	369.800	0.593	-0.339
13	285.980	73.760	295.339	0.379	-2.637
32	-650.000	-138.887	664.673	0.000	95.486
11	0.000	0.000	0.000		
6	363.425	20.229	363.988	1.014	-0.800
10	-363.427	-65.466	369.276	0.593	-0.339
12	0.001	45.237	45.237	0.036	0.971
12	-7.500	-88.000	88.319		
11	0.034	-44.266	44.266	0.036	0.971
13	-7.534	-43.734	44.379	0.036	0.976
13	0.000	0.000	0.000		
10	-285.601	-76.397	295.642	0.379	-2.637
14	278.031	31.687	279.830	0.774	-6.998
12	7.570	44.710	45.347	0.036	0.976
14	0.000	0.000	0.000		
4	269.861	37.615	272.470	0.661	-1.741
13	-277.256	-38.685	279.942	0.774	-6.998
15	7.395	1.070	7.472	0.007	-32.872
15	-320.000	-153.000	354.696		
14	-7.388	-33.942	34.737	0.007	-32.872
16	-312.612	-119.058	334.516	1.106	-4.022
16	-329.000	-32.300	330.582		
15	313.718	115.036	334.144	1.106	-4.022
17	230.494	-60.279	238.246	0.425	-7.052
19	-502.095	-35.931	503.379	4.372	24.659
21	-328.465	35.266	330.353	0.953	-7.401
24	-42.651	-86.392	96.347	0.028	-5.761
17	0.000	0.000	0.000		
16	-230.070	53.226	236.147	0.425	-7.052
18	208.966	-6.651	209.072	0.328	-8.420
27	21.104	-46.575	51.134	0.020	-29.845
18	-158.000	-30.000	160.823		
3	50.638	-28.231	57.976	0.034	-19.479
17	-208.638	-1.769	208.645	0.328	-8.420
19	0.000	0.000	0.000		
16	506.468	60.590	510.079	4.372	24.659
33	-629.063	-82.369	634.433	2.937	59.579
20	122.595	21.779	124.515	0.113	2.230
20	-628.000	-103.000	636.391		
34	-505.518	-83.451	512.360	2.482	49.640
19	-122.482	-19.549	124.032	0.113	2.230
21	-274.000	-115.000	297.155		
16	329.418	-42.667	332.170	0.953	-7.401
22	-603.418	-72.333	607.738	3.202	32.014
22	0.000	0.000	0.000		
21	606.620	104.347	615.529	3.202	32.014
23	43.380	25.408	50.273	0.019	-17.229
35	-650.000	-129.755	662.825	0.000	65.891
23	-247.500	-84.600	261.560		
22	-43.361	-42.636	60.811	0.019	-17.229
24	354.204	1.205	354.206	2.924	12.573
36	-558.343	-43.168	560.009	1.657	90.132
24	-308.600	92.000	322.022		
16	42.680	80.631	91.230	0.028	-5.761
23	-351.280	11.369	351.464	2.924	12.573
25	-224.000	-47.200	228.919		
2	244.256	-75.204	255.571	4.534	-8.760
26	69.987	-3.567	70.078	0.173	-48.698
37	-538.242	31.571	539.168	1.758	67.958

26	-139.000	-17.000	140.036		
25	-69.813	-45.131	83.131	0.173	-48.698
27	261.018	80.848	273.252	1.102	-11.383
28	-140.507	-24.706	142.663	0.879	-66.490
29	-189.697	-28.011	191.754	2.134	-77.314
27	-281.000	-75.500	290.966		
17	-21.084	16.731	26.915	0.020	-29.845
26	-259.916	-92.231	275.795	1.102	-11.383
28	-206.000	-27.600	207.841		
26	141.386	-41.784	147.431	0.879	-66.490
29	-347.386	14.184	347.676	1.737	-5.691
29	-283.500	-26.900	284.773		
26	191.831	-49.304	198.066	2.134	-77.314
28	349.123	-19.874	349.688	1.737	-5.691
38	-824.454	42.278	825.537	5.546	108.145
30	250.000	87.276	264.796		
2	250.000	87.277	264.797	0.000	12.691
<b>Total loss</b>		<b>48.310</b>		<b>36.862</b>	

## VII. CONCLUSION

This paper presents the use of Dijkstra's Algorithm for service restoration plan after a complete blackout by application of graph theory the process had been made simple and user friendly. In order to demonstrate the efficiency of Dijkstra's algorithm it has been applied to IEEE 10 Generator 39 Bus System. We carry out three stages of recovery process by using Dijkstra's algorithm. Newton-Raphson method is used to carry out load flow analysis. The simulation results show that Newton-Raphson method is effective and promising. It has been found that by application of Dijkstra's algorithm the transmission losses can be reduced to significant extent. The advantages are (1) solution procedure leads to the optimum solution and (2) avoid combinational explosion of the number of the number of configurations to be tested. This it is believed that the results from Dijkstra's algorithm in power system restoration results in better plan, so it can be considered for real time application. Since the simulation implementation is done only for 39 bus system it can be extended to networks with more number of buses.

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