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Open Circuit Fault Analysis of Electrical Power System Using MATLAB

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***Abstract*—The present paper is devoted to study the behavior of power system under abnormal conditions of open circuit of transmission lines. Open circuit faults have been simulated on standard IEEE 11 bus system and 30 bus systems. State of the system before and after the fault has been estimated in terms of bus voltages and line losses by solving load flow. Newton – Raphson method is implemented using MATLAB to solve load flow problem. Open circuit conditions have been simulated on the lines one by one and their effect on the bus voltages has been observed and most critical lines are sorted out. To bring the voltages back with-in normal range, load shedding technique has been suggested. The criterion is to find the bus from which the load is to be shut down for the repairing time of the faulty line so as to bring the voltage magnitude within limits at other buses so that whole power system is avoided from ill-effects of fault. It is observed that line losses tend to increase due to fault but after load shedding these come with-in same range as before the fault. The analysis of a power system under open circuit faulty conditions is therefore important to determine the values of system voltages, so that protective measures are taken to minimize the harmful effects of such contingencies.**

Keywords*—Bus voltages, Load flow, Open circuit, Transmission line, Under-voltag, Load Shedding.

I. INTRODUCTION

Power system continues to increase in size and complexity due to technological development. Every year many more power stations, transmission lines and substations are constructed due to the increase in demand for electrical energy. This situation increases the fault levels in power systems [1]. An electric power system should ensure the availability of electrical energy without interruption to every load connected to the system. When the electric power supply is extended to remote villages the power system would consist of several thousand Kilometers of distribution lines. The high voltage transmission lines carrying bulk power could extend over several hundred Kilometers. Since all these lines are generally overhead lines and are exposed, there are many chances of their breakdown due to storms, falling of external objects, damage to the insulators, etc. These can result not only in mechanical damage but also in an electrical fault [2]. Open Circuit fault occurs if a circuit is interrupted by some failure. The effects of faults on power system are:

(i) Due to overheating and mechanical forces developed by faults, electrical equipments such as bus-bars, generators and transformers may be damaged.

(ii) The voltage profile of the system may be reduced to unacceptable limits as a result of fault. A frequency drop may lead to instability [3].

The purpose of an electrical power system is to generate and supply electrical energy to consumers with reliability and economy.

In this paper, open circuit fault analysis on power system is done by using MATLAB programming. MATLAB is a powerful software package used for high performance scientific numerical computation, data analysis and visualization[4][5].

II. PROBLEM FORMULATION

When a transmission line is open circuited, during such an emergency situation, the operating personnel are often burdened with a large volume of data and are under pressure of taking immediate decisions. Decisions under such critical conditions are not taken until the voltage problems in the network are not diagnosed. Therefore, in this paper the voltage magnitudes at buses during opening of transmission lines one by one has been computed and it has been studied that voltage on which bus fall below the acceptable level and then secondly, optimum load shedding is done to stabilize the voltage magnitude. The main objective of load shedding, in case the state of operation of the power system goes down to its critical level, is to keep the system operative after a contingency.

III. RESEARCH WORK

Open circuit fault analysis has been performed on standard IEEE 11 bus system and IEEE 30 bus system:

(i) Bus admittance matrix
(ii) Newton Raphson method for load flow
(iii) Open circuit fault analysis

Then compare the load flow programming results with the open circuit fault programming results. The single line diagram for standard 11 bus system and IEEE 30 bus system is shown in Fig. 1 and Fig.2. In 11 bus system, there are 17 no. of transmission lines, 5 PV buses and 6 PQ buses. In 30 bus system, there are 41 no. of transmission lines, 6 PV buses and 24 PQ buses.

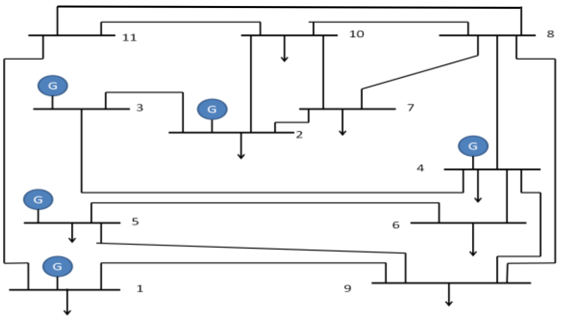

Figure1: One line diagram for 11 bus system

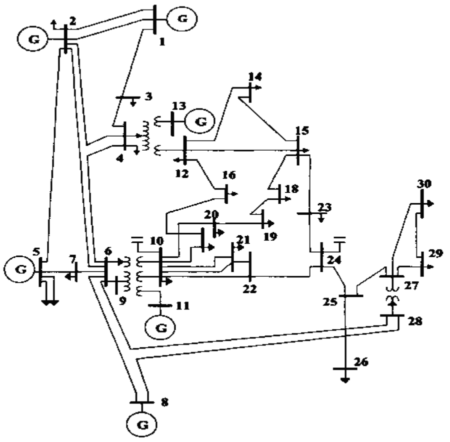

Figure2: One line diagram for IEEE 30 bus system

IV. LOAD FLOW ANALYSIS

Load Flow Problem : In PQ buses, P and Q are specified where as the unknowns V and δ are determined by load flow solution. In PV buses, the knowns are P and V and unknowns are Q and δ. For Slack bus, it is assumed that the V and δ are known, where as P and Q are obtained through the load flow solution.

The complex power injected by the source into ith bus of a power system is,

$S_i = P_i + Q_i = V_i J_i^*$ i=1,2,3,…….n (1)

Where V_i is the voltage at ith bus with respect to ground and J_i is the source current injected into the bus.

The load flow problem is handled more conveniently by use of J_i rather than Ji^*. Therefore, taking the complex conjugate of eq(1), we have

$P_i - Q_i = V_i^* J_i$; i=1,2,3,…….n

Where ‘n’ is the number of buses in the power system network.

Substituting for $J_i = \sum_{k=1}^{n} Y_{ik} V_k$, we can write,

$P_i - Q_i = V_i \sum_{k=1}^{n} Y_{ik} V_k$

Real and Reactive powers can be expressed as,

$$P_i = |V_i| \sum_{k=1}^{n} |V_k||Y_{ik}| \cos(\theta_{ik} + \delta_k - \delta_i) \quad (2)$$

$$Q_i = -|V_i| \sum_{k=1}^{n} |V_k||Y_{ik}| \sin(\theta_{ik} + \delta_k - \delta_i) \quad (3)$$

For static load flow solution to have practical significance, all the state and control variables must lie within specified practical limits. These limits, dictated by specifications of power system hardware and operating constraints, are described below:

i. Voltage manitude $|V_i|$ must satisfy the inequality constraints.

ii. $|V_i|_{min} \leq |V_i| \leq |V_i|_{max.}$

The power system equipment is designed to operate at fixed voltages with allowable variations of ± 10% as per rated KV.

iii. Certain of δ_i (state variable) must satisfy the inequality constraint

$|\delta i - \delta k| \leq |\delta i - \delta k|_{max.}$

This constraint limits the maximum permissible limits of power flow on a transmission line connecting buses i and k and is imposed due to considerations of system stability.

Load flow solution: It is a technique that provides basic calculation procedure in order to determine the characteristics of power system under steady state condition [6][7].

Newton Raphson method is adopted for large networks due to;

- Quadratic convergence characteristics.
- High accuracies obtained in a few iterations.
- No. of iterations independent of the size of the system.

Newton Raphson Method: This method begins with initial guesses of all unknown variables(V, δ at PQ buses and δ at PV buses). Next a Taylor series is written, with higher order terms ignored, for each of the power balance equations included in the system of equations. The result is linear system of equations that can be expressed as :

$$\begin{bmatrix} \Delta P \\ \Delta Q \end{bmatrix} = [-J] \begin{bmatrix} \Delta \delta \\ \Delta V \end{bmatrix} \quad (4)$$

Where ΔP & ΔQ are called mismatch equations and J is a matrix of partial derivatives known as Jacobian

$$J = \begin{bmatrix} \partial \Delta P / \partial \delta & \partial \Delta P / \partial V \\ \partial \Delta Q / \partial \delta & \partial \Delta Q / \partial V \end{bmatrix}$$

Pi and Qi are calculated from equation (2) and (3).

ΔPi = Pi(specified)- Pi (calculated)

ΔQi = Qi(specified)- Qi(calculated)

The linearized system of equations is solved to determine the next guess (r+1) of voltage magnitude and angles. The process continues un till a stopping condition is met [7]. A common stopping condition is to terminate if the mismatch equations are below a specified tolerance. A solution of the power flow problem using Newton Raphson method is depicted in Fig. 2:

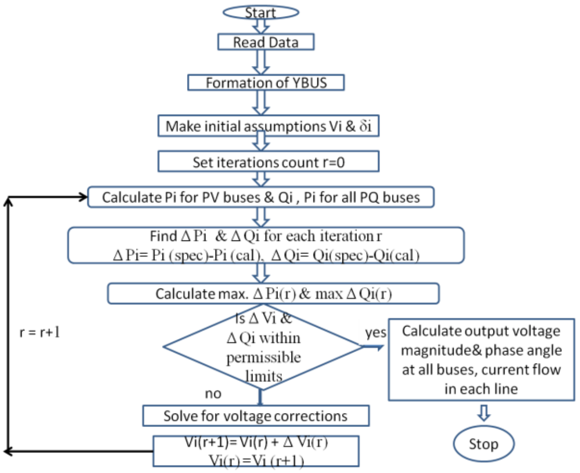

Figure 3: Flow Chart for Newton Raphson Load Flow Method

V. ALGORITHM FOR OPEN CIRCUIT FAULT ANALYSIS

Algorithm adopted for this type of analysis consists following steps;

1) Find pre-fault conditions of voltage at each bus and real power losses in the system.
2) Specify the open circuited line and re-compute the bus admittance matrix.
3) Run the program for open circuit analysis.
4) Compare the voltage magnitudes of pre-fault and post fault conditions.
5) Observe that on which buses voltage magnitude falls below the acceptable levels of ±10%.
6) Note down those buses & their voltage magnitudes. Voltages at these buses is upgraded by removing the load (until the line is not repaired) from those buses or from buses which are nearer to them.

VI. METHODLOGY

Initially load flow solution of the power system is obtained under normal conditions by using Newton-Raphson method. Numerical computations are done by using MATLAB. Bus voltages and Powers are calculated under normal conditions by solving equations (2), (3) and (4) Then fault conditions have been simulated by opening the lines one by one. Each time when a line is opened, load flow program is re-run. Opening of a line affects the admittance of the network, which in turn affects the power flow on transmission lines and bus voltages. It also affects the power loss of the system. To bring the system back to normal operating conditions during fault, effect of load shedding on bus voltages and power losses has been studied and discussed below.

VII. RESULTS AND DISCUSSION

It is observed that some lines of the system are most critical. In case of IEEE 11 bus 17 transmission line system only line no. 2 is most critical i.e. by open circuiting this line, voltages on the buses are going out of limits. Then to make the voltage magnitude as normal, load shedding criterion is implemented on each bus. This criterion is used to find out the bus from which the load is to be shut down to stabilize the voltage magnitude at other buses. Same methodology has been implemented on IEEE 30 bus 41 transmission lines system, there are three lines that are most critical i.e. line no. 1, 26 and 36. The results for these affected lines are discussed below.

Firstly, discuss the results for 11 bus system, when line no. 2 (connected between bus no. 1 and 11) is open circuited as shown in table1. It is seen that voltage magnitudes at bus no. 7,8 and 11 fall below the acceptable levels of ±10% and it is observed that by reducing the load demand from bus no.7 and bus no.11 for some time (repairing time of that faulty line), voltage magnitudes on bus no.7,8 and 11 becomes as normal one as shown in table 1 . This effect is shown graphically in Fig.4. As seen from table 2, while comparing with pre-fault losses, real power loss on the system increases as line no.2 is open circuited and after the load shedding losses are reduced.

Table 3, shows the effect on real power losses of 30 bus system after opening a line and after reducing the load. Table 4, shows the results for IEEE 30 bus system and it is seen that during the outage of line no. 1 (that is connected between bus no. 1 and 2) then voltage magnitudes at each bus fall below the acceptable levels of ±10% except buses 1,2,5 and 7 and it is observed that by reducing the load demand from bus no.5 for repairing time of that faulted line, effected voltage magnitudes becomes as normal one. This effect is shown graphically in Fig.5.

Table 1: Effect on bus voltage magnitude (p.u.) on 11 bus system during one line open circuited and after load shedding.

Bus no.	Pre-fault Voltage obtained from loadflow (p.u)	Effect on bus voltage magnitude after opening line no.2 (p.u)	Effect on bus voltage magnitude after load shedding (p.u.)
1	1.0700	1.0700	1.0700
2	1.0924	0.9793	1.1050
3	1.0950	1.0950	1.0950
4	1.0620	1.0228	1.0620
5	1.0460	1.0460	1.0460
6	1.0501	1.0281	1.0496
7	**1.0118**	**0.8971**	**1.0371**
8	**0.9890**	**0.8834**	**0.9978**
9	0.9983	0.9644	0.9981
10	1.0326	0.9120	1.0435
11	**1.0310**	**0.8734**	**1.0194**

Table 2: Effect on real power losses of 11 bus system

Real Power Loss from load flow analysis on normal system	Real Power Loss when line no. 2 is open circuited.	Real Power Loss after load shedding
0.1145 p.u.	**0.1942 p.u.**	0.1142 p.u.

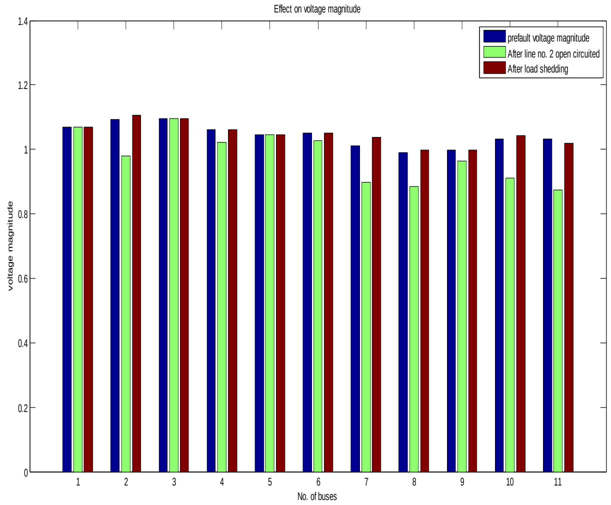

Figure 4: Graph between voltage magnitudes and no. of buses of 11 bus system during line no. 2 is open circuited and during load shedding

Table3: Effect on real power losses of 30 bus system during outage of line no. 1 and after load shedding.

Real Power Loss from load flow analysis on normal system	Real Power Loss when line no. 1 is open circuited.	Real Power Loss after load shedding
0.1795 p.u.	**9.0181 p.u.**	0.2016 p.u.

Table 4: Effect on bus voltage magnitude (p.u.) of 30 bus system during line no.1 open circuited and after load shedding.

Bus No.	Pre-fault Voltage obtained from loadflow (p.u)	Effect on bus voltage magnitude after opening line no.1 (p.u)	Effect on bus voltage magnitude after load shedding (p.u.)
1	1.0600	1.0600	1.0600
2	1.0450	1.2022	1.0294
3	**1.0213**	0.5199	**1.0052**
4	**1.0118**	0.8055	**0.9992**
5	1.0100	1.1700	1.0100
6	**1.0027**	0.8162	**0.9977**
7	0.9970	0.9338	0.9946
8	**0.9989**	0.8027	**1.0002**
9	**1.0012**	0.4188	**0.9984**
10	**0.9778**	0.5137	**0.9740**
11	**1.0465**	0.1943	**1.0477**
12	**1.0113**	0.7116	**1.0099**
13	**1.0468**	0.7015	**1.0511**
14	**0.9927**	0.6778	**0.9913**
15	**0.9853**	0.6542	**0.9831**
16	**1.0042**	0.7018	**1.0031**
17	**0.9698**	0.5058	**0.9659**
18	**0.9697**	0.5928	**0.9669**
19	**0.9638**	0.5584	**0.9607**
20	**0.9665**	0.5466	**0.9632**
21	**0.9648**	0.5126	**0.9611**
22	**0.9655**	0.5176	**0.9618**
23	**0.9683**	0.6104	**0.9656**
24	**0.9546**	0.5582	**0.9512**
25	**0.9587**	0.6138	**0.9547**
26	**0.9399**	0.5889	**0.9358**
27	**0.9703**	0.6606	**0.9661**
28	**0.9971**	0.7934	**0.9936**
29	**0.9493**	0.6301	**0.9450**
30	**0.9371**	0.6117	**0.9327**

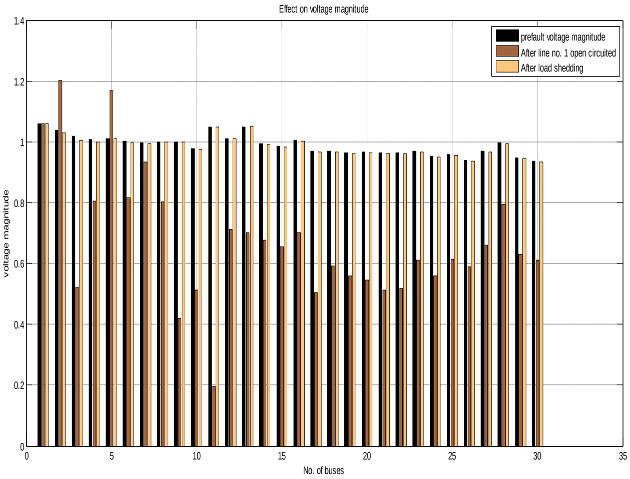

Figure 5: Graph between voltage magnitudes and no. of buses of 30 bus system during line no. 1 is open circuited and during load shedding

Table 5: Effect on real power losses of 30 bus system during outage of line no. 26 and after load shedding.

Real Power Loss from load flow analysis on normal system	Real Power Loss when line no. 26 is open circuited.	Real Power Loss after load shedding
0.1795 p.u.	**0.3025 p.u**.	0.1625 p.u.

Table 5&7 shows the effect on real power losses of 30 bus system after opening line no.26 & 36 and after reducing the load. From table 6, it is seen that during the outage of line no. 26 (that is connected between bus no. 10 and 17) then voltage magnitudes at bus no. 17 fall below the acceptable level and it is observed that by reducing the load demand from bus no. 10 and 17 for repairing time of that faulted line, affected voltage magnitudes becomes as normal.

Table 6: Effect on bus voltage magnitude (p.u.) of 30 bus system during line no.26 open circuited and after load shedding.

Bus No.	Pre-fault Voltage obtained from loadflow (p.u)	Effect on bus voltage magnitude after opening line no.26 (p.u)	Effect on bus voltage magnitude after load shedding (p.u.)
1	1.0600	1.0600	1.0600
2	1.0450	1.0385	1.0450
3	1.0213	1.0162	1.0245
4	1.0118	1.0063	1.0163
5	1.0100	1.0100	1.0100
6	1.0027	1.0017	1.0097
7	0.9970	0.9973	1.0021
8	0.9989	1.0009	1.0064
9	1.0012	1.0069	1.0173
10	0.9778	0.9866	0.9989
11	1.0465	1.0529	1.0614
12	1.0113	0.9983	1.0191
13	1.0468	1.0376	1.0546
14	0.9927	0.9818	1.0021
15	0.9853	0.9777	0.9963
16	1.0042	0.9609	1.0102
17	**0.9698**	**0.0837**	**0.9073**
18	0.9697	0.9680	0.9845
19	0.9638	0.9656	0.9808
20	0.9665	0.9700	0.9845
21	0.9648	0.9727	0.9853
22	0.9655	0.9730	0.9857
23	0.9683	0.9651	0.9815
24	0.9546	0.9570	0.9706
25	0.9587	0.9602	0.9707
26	0.9399	0.9415	0.9522
27	0.9703	0.9713	0.9798
28	0.9971	0.9969	1.0048
29	0.9493	0.9503	0.9590
30	0.9371	0.9381	0.9470

Table 7: Effect on real power losses of 30 bus system during outage of line no. 36 and after load shedding.

Real Power Loss from load flow analysis on normal system	Real Power Loss when line no. 26 is open circuited.	Real Power Loss after load shedding
0.1795 p.u.	**0.2103 p.u.**	0.1787 p.u.

From table 8, it is seen that during the outage of line no. 36 (that is connected between bus no. 28 and 27) then voltage magnitudes at bus no. 25,26,27,29 and 30 fall below the acceptable levels of ±10% and it is observed that by reducing the load demand from bus no. 29 and 30 for repairing time of that faulted line, affected voltage magnitudes becomes as normal one.

Table 8: Effect on bus voltage magnitude (p.u.) of 30 bus system during line no.36 open circuited and after load shedding.

Bus No.	Pre-fault Voltage obtained from loadflow (p.u)	Effect on bus voltage magnitude after opening line no.36 (p.u)	Effect on bus voltage magnitude after load shedding (p.u.)
1	1.0600	1.0600	1.0600
2	1.0450	1.0379	1.0450
3	1.0213	1.0165	1.0330
4	1.0118	1.0066	1.0264
5	1.0100	1.0100	1.0100
6	1.0027	1.0010	1.0257
7	0.9970	0.9968	1.0116
8	0.9989	1.0015	1.0363
9	1.0012	0.9910	1.0138
10	0.9778	0.9608	0.9890
11	1.0465	1.0430	1.0519
12	1.0113	1.0033	1.0193
13	1.0468	1.0445	1.0512
14	0.9927	0.9809	1.0005
15	0.9853	0.9681	0.9921
16	1.0042	0.9963	1.0124
17	0.9698	0.9526	0.9811
18	0.9697	0.9524	0.9782
19	0.9638	0.9464	0.9733
20	0.9665	0.9492	0.9764
21	0.9648	0.9414	0.9740
22	0.9655	0.9401	0.9740
23	0.9683	0.9352	0.9716
24	0.9546	0.9009	0.9531
25	**0.9587**	**0.8334**	**0.9338**
26	**0.9399**	**0.8117**	**0.9145**
27	**0.9703**	**0.8050**	**0.9317**
28	0.9971	1.0024	1.0295
29	**0.9493**	**0.7789**	**0.9296**
30	**0.9371**	**0.7639**	**0.9284**

VIII. CONCLUSION

Above results shows that voltage magnitude at buses decreases during the outage of transmission lines. After the appropriate load shedding, voltages are again within the range of acceptable limits. Information gained from above results can be utilized to determine the effect on voltage at each bus of the system during open circuit faults and to take effective immediate decisions to make the voltages at all buses as normal one. Study can help to take quick decisions to avoid or minimize ill effects of power system faults.

APPENDIX
TEST SYSTEM DATA

Open circuit fault analysis has been done on two standard IEEE test systems of 11 bus 17 line system and 30 bus 41 line system. Line data and load data for these test systems is given below:

Table 9: Line data for standard IEEE 11 bus system.

Line no.	Branch(p-q)	Line charging Y_{pq}	Impedance Z_{pq}
1	1-9	j0.030	0.15+j0.50
2	1-11	j0.010	0.05+j0.16
3	2-3	j0.030	0.15+j0.50
4	2-7	j0.020	0.10+j0.28
5	2-10	j0.010	0.05+j0.16
6	3-4	j0.015	0.08+j0.24
7	4-6	j0.020	0.10+j0.28
8	4-8	j0.020	0.10+j0.28
9	4-9	j0.030	0.15+j0.50
10	5-6	j0.025	0.12+j0.36
11	5-9	j0.010	0.05+j0.16
12	7-8	j0.010	0.05+j0.16
13	7-10	j0.015	0.08+j0.24
14	8-9	j0.025	0.12+j0.36
15	8-10	j0.015	0.08+j0.24
16	8-11	j0.020	0.10+j0.28
17	10-11	j0.025	0.12+j0.36

Table 10: Load data for standard IEEE 11 bus system.

Bus no.	Generation (p.u.)		Load (p.u.)		Bus Voltage	
	P_g	Q_g	P_d	Q_d	V (p.u)	δ (rad)
1	-	-	0.00	0.00	1.070	0
2	0.6625	-	0.00	0.00	1.089	-
3	0.6625	-	0.00	0.00	1.095	-
4	0.4778	-	0.00	0.00	1.062	-
5	0.4778	-	0.00	0.00	1.046	-
6	0.0000	0.0	0.10	0.02	-	-
7	0.0000	0.0	0.40	0.10	-	-
8	0.0000	0.0	0.90	0.45	-	-
9	0.0000	0.0	0.70	0.35	-	-
10	0.0000	0.0	0.25	0.05	-	-
11	0.0000	0.0	0.25	0.05	-	-

TABLE 11: LINE DATA FOR STANDARD IEEE 11 BUS SYSTEM.

Line no.	From Bus	To Bus	Line Impedance		Half Line Charging Susceptance (p.u.)
			R(p.u.)	X(p.u.)	
1	1	2	0.0192	0.0575	0.0264
2	1	3	0.0452	0.1652	0.0204
3	2	4	0.0570	0.1737	0.0184
4	3	4	0.0132	0.0379	0.0042
5	2	5	0.0472	0.1983	0.0209
6	2	6	0.0581	0.1763	0.0187
7	4	6	0.0119	0.0414	0.0045
8	5	7	0.0460	0.1160	0.0102
9	6	7	0.0267	0.0820	0.0085
10	6	8	0.0120	0.0420	0.0045
11	6	9	0	0.2080	0
12	6	10	0	0.5560	0
13	9	11	0	0.2080	0
14	9	10	0	0.1100	0
15	4	12	0	0.2560	0
16	12	13	0	0.1400	0
17	12	14	0.1231	0.2559	0
18	12	15	0.0662	0.1304	0
19	12	16	0.0945	0.1987	0
20	14	15	0.2210	0.1997	0
21	16	17	0.0524	0.1923	0
22	15	18	0.1073	0.2185	0
23	18	19	0.0639	0.1292	0
24	19	20	0.0340	0.0680	0
25	10	20	0.0936	0.2090	0
26	10	17	0.0324	0.0845	0
27	10	21	0.0348	0.0749	0
28	10	22	0.0727	0.1499	0
29	21	22	0.0116	0.0236	0
30	15	23	0.1000	0.2020	0
31	22	24	0.1150	0.1790	0
32	23	24	0.1320	0.2700	0
33	24	25	0.1885	0.3292	0
34	25	26	0.2544	0.3800	0
35	25	27	0.1093	0.2087	0
36	28	27	0	0.3960	0
37	27	29	0.2198	0.4153	0
38	27	30	0.3202	0.6027	0
39	29	30	0.2399	0.4533	0
40	8	28	0.0636	0.2000	0.0214
41	6	28	0.0169	0.0599	0.0065

Table 12: Load data for standard IEEE 30 bus system.

Bus no.	BUS VOLTAGE		Generation (P.U.)		Load (P.U.)	
	MAG.	ANG	P_G	Q_G	P_D	Q_D
1	1.060	0	1.3848	-0.0279	0.000	0.000
2	1.045	0	0.4000	0.500	0.217	0.127
3	1.000	0	0.0000	0.000	0.024	0.012
4	1.060	0	0.0000	0.000	0.076	0.016
5	1.010	0	0.0000	0.370	0.942	0.19
6	1.000	0	0.0000	0.000	0.000	0.000
7	1.000	0	0.0000	0.000	0.228	0.109
8	1.010	0	0.0000	0.373	0.3	0.3
9	1.000	0	0.0000	0.000	0.000	0.000
10	1.000	0	0.0000	0.000	0.058	0.02
11	1.082	0	0.0000	0.162	0.000	0.000
12	1.000	0	0.0000	0.000	0.112	0.075
13	1.071	0	0.0000	0.106	0.000	0.000
14	1.000	0	0.0000	0.000	0.062	0.016
15	1.000	0	0.0000	0.000	0.082	0.025
16	1.000	0	0.0000	0.000	0.035	0.018
17	1.000	0	0.0000	0.000	0.09	0.058
18	1.000	0	0.0000	0.000	0.032	0.009
19	1.000	0	0.0000	0.000	0.095	0.034
20	1.000	0	0.0000	0.000	0.022	0.007
21	1.000	0	0.0000	0.000	0.175	0.112
22	1.000	0	0.0000	0.000	0.000	0.000
23	1.000	0	0.0000	0.000	0.032	0.016
24	1.000	0	0.0000	0.000	0.087	0.067
25	1.000	0	0.0000	0.000	0.000	0.000
26	1.000	0	0.0000	0.000	0.035	0.023
27	1.000	0	0.0000	0.000	0.000	0.000
28	1.000	0	0.0000	0.000	0.000	0.000
29	1.000	0	0.0000	0.000	0.024	0.009
30	1.000	0	0.0000	0.000	0.106	0.019

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