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Short Circuit Fault Analysis of Electrical Power System using MATLAB

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Abstract: *The objective of the present study is to simulate short circuit faults on different buses of a power system network and to estimate the state of the power system before and after a fault, which includes various bus voltages and current flow on various transmission lines. The analysis before the fault is carried out by solving non-linear load flow problem by using numerical iterative technique of Newton-Raphson method. State estimation after short circuit fault is carried by using algorithm of short circuit current computation. The short circuit currents dictate the rating of circuit breakers to be employed at various buses and in various lines of the network. The effect of three phase short circuit faults on power system has been studied in terms of post-fault conditions and pre-fault conditions. In this paper, three phase short circuit fault is simulated on the standard IEEE 11bus and IEEE 30 bus system and fault current level is calculated and short circuit MVA rating for the circuit breaker has been chosen. The analysis of power system under faulty conditions is important to determine the values of system voltages and currents during faulted conditions, so that protective devices may be set to minimize the harmful effects of such contingencies.*

Keywords*: Load flow, Short circuit current, SCMVA ratings of circuit breakers, Three phase fault calculation.*

I. INTRODUCTION

Electrical energy consumption increases more and more on a daily basis. Technological development is the reason for the use of electrical energy. Every year many more power stations, transmission lines and substations are constructed. This situation increases the fault current levels in power systems. A power system is not static but changes during operation (switching on or off of generators and transmission lines) and during planning (addition of generators and transmission lines).Thus fault studies need to be routinely performed by utility engineers [1].

A Fault is defined as any failure which interferes with the normal current flow[2]. Various types of faults occur on power system are shown in fig. 1 Short circuit fault is a fault in which current flow bypasses the normal load and an Open circuit fault occurs if a circuit is interrupted by some failure. Fault analysis can be broadly grouped into symmetrical and unsymmetrical faults. A balanced three phase fault occurs when there is a simultaneous short circuit across all three phases. This type of fault is also called Symmetrical fault. If only some phases are affected, the resulting Unsymmetrical fault [1][3]. Majority of fault occurring on power system are unsymmetrical faults, however, the circuit breaker rated MVA breaking capacity is based on three-phase symmetrical faults. The reason is that a three-phase fault produces the greatest fault current and Circuit Breaker must be capable of interrupting it[4].

The causes of faults are numerous and they include lightning, insulation aging, heavy winds, trees falling across lines, vehicles colliding with poles, birds, kites, etc. The effects of faults on power system are:
(i) Overheating and mechanical forces developed by faults may damage the electrical equipment such as bus-bars, generators and transformers.
(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 [5].

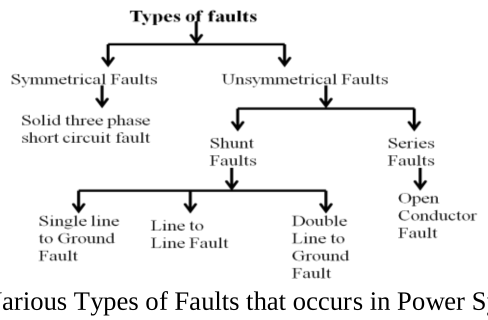

Figure 1: Various Types of Faults that occurs in Power System

1.1 USE OF SIMULATION SOFTWARE

In this paper, short 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.

The single line diagram for standard IEEE 11 bus and IEEE 30 bus system is shown in Fig. 2 and Fig.3.

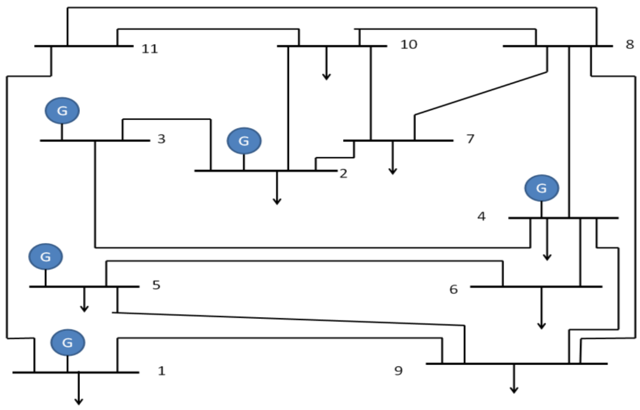

Figure2: One line diagram for 11 bus system

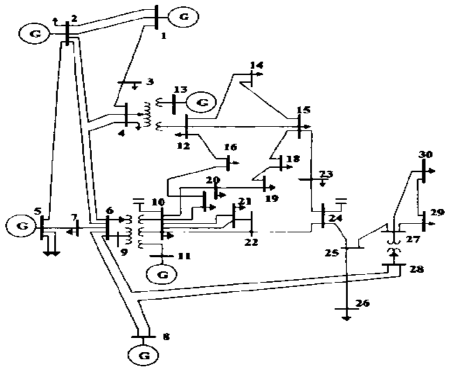

Figure3: One line diagram for IEEE 30 bus

1.2 NEED FOR FAULT ANALYSIS IN PLANNING AND OPERATION OF POWER SYSTEM

The system being planned is to be optimal with respect to construction cost, performance and operating efficiency. For this better planning tools are required. In general, the major power system tools are: load Flow Analysis, short circuit analysis or fault calculations, stability analysis etc.

The purpose of an electrical power system is to generate and supply electrical energy to consumers with reliability and economy. The greatest threat to this purpose of a power system is the short circuit [3]. The evaluation of fault currents on a power system is significant because the protective devices to be installed on the system depend on the values of the fault currents. Information gained from fault analysis used to select the appropriate size and type of protective equipments to be installed on the system so that the continuity of supply is ensured even when there is a fault on the power system.

II. Short Circuit Fault Analysis Problem Formulation

2.1 PRELIMINARY CALCULATIONS

In the fault studies, it is necessary to have the knowledge of pre-fault voltages and currents. These pre-fault conditions can be obtained from the results of load flow studies by the Newton Raphson method. Load flow analysis is a technique that provides basic calculation procedure in order to determine the characteristics of power system under steady state condition [8]. A solution of the power flow problem using Newton Raphson method is depicted in Fig. 4. The Newton Raphson method is adopted for large networks due to its quadratic convergence characteristics, high accuracies obtained in a few iterations and no. of iterations independent of the size of the system [4].

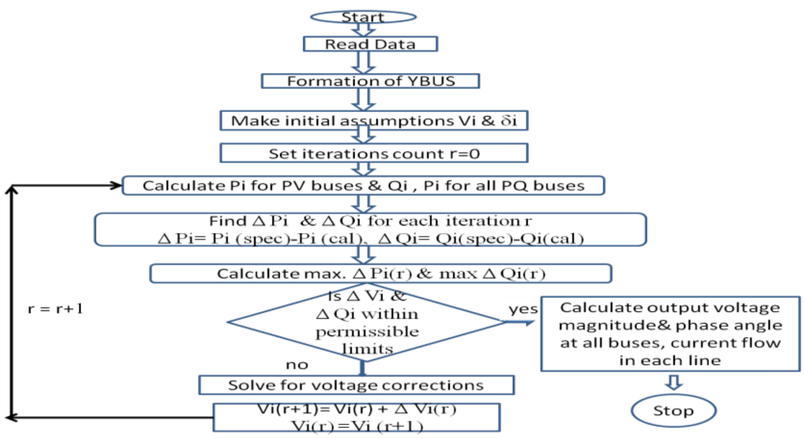

Figure 4: Flow Chart for Newton Raphson Load Flow Method

2.2 CALCULATION OF SHORT CIRCUIT CURRENTS

If the insulation of system fails at any point or if two or more conductor that normally operates with a potential difference comes in contact with each other , a short circuit is said to be occur. Fault analysis calculate the fault currents magnitudes that are used to determine short circuit megavolt ampere(SCMVA) ratings of appropriate circuit breakers[9][10]. For a symmetrical fault, the negative and zero sequences are absent. The positive sequence present and modified for fault analysis as shown in Fig.5:

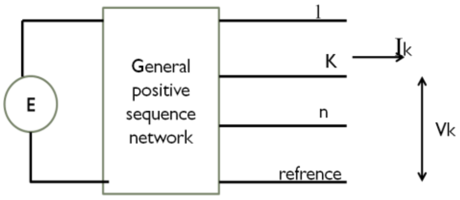

Figure 5: Positive Sequence Network Modified for Fault Analysis[11]

The injected bus currents in terms of bus voltages for a n-bus network is calculated as;

$$I_{bus} = Y_{bus} .V_{bus} \quad (1)$$

Where I_{bus} is the bus current vector entering the bus & Y_{bus} is the bus admittance matrix

For a fault at bus k, the current entering every bus except the faulted bus k is zero thus equation (1) becomes:

$$\begin{bmatrix} 0 \\ 0 \\ \vdots \\ -\mathrm{Ik(F)} \\ 0 \end{bmatrix} = \begin{bmatrix} Y11 & \dots & Y1k & Y1n \\ Y21 & \dots & Y2k & Y2n \\ \vdots & \ddots & \vdots & \vdots \\ Yk1 & \dots & Ykk & Ykn \\ Yn1 & \dots & Ynk & Ynn \end{bmatrix} \begin{bmatrix} \Delta V1 \\ \Delta V2 \\ \vdots \\ \Delta Vk \\ \Delta Vn \end{bmatrix} \quad (2)$$

Equation (2) can be written as

$$I_{bus}(F) = Y_{bus} .\Delta V_{bus} \quad (3)$$

From above equation ;

$$\Delta V_{bus} = \text{inverse}(Y_{bus}).\ I_{bus}(F)$$
$$= Z_{bus} .\ I_{bus}(F) \quad (4)$$

$Z_{bus} = \text{inverse}(Y_{bus})$ is the bus impedance matrix

$$V_{bus}(F) = V_{bus}(0) + \Delta V_{bus} \quad (5)$$

Substituting (4) into equation (5) gives;

$$V(F)= V_{bus}(0)+Z_{bus}.I_{bus}(F) \quad (6)$$

Above equation (6) can be written in matrix form as;

$$\begin{bmatrix} V1(F) \\ V2(F) \\ \vdots \\ Vk(F) \\ Vn(F) \end{bmatrix} = \begin{bmatrix} V1(0) \\ V2(0) \\ \vdots \\ Vk(0) \\ Vn(0) \end{bmatrix} + \begin{bmatrix} Z11 & \dots & Z1k & Z1n \\ Z21 & \dots & Z2k & Z2n \\ \vdots & \ddots & \vdots & \vdots \\ Zk1 & \dots & Zkk & Zkn \\ Zn1 & \dots & Znk & Znn \end{bmatrix} \begin{bmatrix} 0 \\ 0 \\ \vdots \\ -\mathrm{Ik(F)} \\ 0 \end{bmatrix}$$

The voltage at bus k during the fault is Vk(F). So;

$$V_k(f) = V_k(0) - Z_{kk}.\ I_k(F) \quad (7)$$

But $V_k(F)= Z^f.I_k(F)$, where Z^f is fault impedance & Where Z_{kk} is k^{th} k^{th} element of bus impedance matrix and this equation put in above equation (7)

Equation (7) becomes;

$$Z^f.I_k(F) = V_k(0) - Z_{kk}.\ I_k(F)$$

Solving for $I_k(F)$ gives;

$$\mathbf{I_k(F)} = \frac{\mathbf{Vk(0)}}{(\mathbf{Zkk + Zf})} \quad (8)$$

For bolted or solid fault , $Z^f = 0$ [12]

For any bus i the bus voltage during fault is;

$V_i(F) = V_i(0) - Z_{ik} .\ I_k(F)$, where Z_{ik} is i^{th} k^{th} element of bus impedance matrix.

From equation(8) ;

$$\mathbf{V_i(F)= V_i(0) - Z_{ik} .} \frac{\mathbf{Vk(0)}}{(\mathbf{Zkk + Zf})} \quad (9)$$

The short circuit current in the line connected between bus i and j is;

$$\mathbf{I_{ij}(F)} = \frac{\mathbf{Vi(F) - Vj(F)}}{\mathbf{zij}} \quad (10)$$

where zij is series impedance when line connected between buses i and j.

Flow Chart for the Calculations of Three-Phase Short Circuit Fault is shown in figure 6.

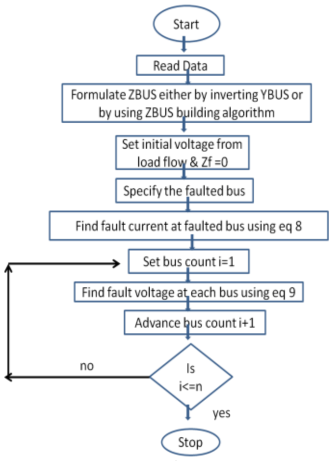

Figure 6: Flow Chart for the Calculations of Three-Phase Short Circuit Fault.

2.3 SELECTION OF CIRCUIT BREAKERS

The circuit breaker has to perform the following major duties under short circuit conditions;

1) To open the contacts to clear the fault.
2) To close the contacts onto a fault.
3) To carry fault current for a short time while another circuit breaker is clearing the fault.

In addition to the rated voltage, current and frequency, circuit breakers have the following important ratings:
1) Breaking capacity 2) Making capacity 3) Short time capacity
The Breaking capacity of a circuit breaker is of two types i.e. Symmetrical Breaking capacity and Asymmetrical Breaking capacity.
Symmetrical breaking capacity: It is the r.m.s value of the ac component of the fault current that the circuit breaker is capable of breaking under specified conditions of recovery voltage.
Asymmetrical breaking capacity: It is the r.m.s value of the total current comprising of both ac and dc components of the fault current that the CB can break under specified conditions of recovery voltage.
The breaking capacity of a CB is generally expressed in MVA.
If voltage & current in p.u. values on a 3ph. Basis,then

SCMVA(3 ph) = | Vprefault | * |Isc|*(MVA base) (11)

Rated MVA interrupting capacity of a CB is to be more than or equal to the short circuit MVA required to be interrupted[4].
The rated asymmetrical breaking capacity is 1.6 times the rated symmetrical current.
Making capacity: The rated making current is defined as the peak value of the current including dc component in the first cycle at which a CB can be closed onto a short circuit.

Making current = √2 * 1.8 * symmetrical breaking current

The multiplication by √2 is obtain the peak value and again by 1.8 to take the d.c. component into account.
Short -time current rating : It is the r.m.s value of total current that the CB can carry safely for a specified short period.

Short time current rating=Breaking current / rated normal current[13].

2.4 A COMPUTATIONAL ALGORITHM FOR SHORT CIRCUIT STUDIES

Algorithm adopted for this type of analysis consists following steps;
STEP 1: Obtain pre-fault voltages at all buses and currents in all lines through a load flow study.
STEP 2: Find Bus impedance matrix by inverting the bus admittance matrix.
STEP 3: Choose MVAbase, KVbase & calculate Ibase.
STEP 4: Specify the faulty bus and obtain current at the faulty bus using equation (8) and bus voltages during fault at all buses using equation (9).
STEP 5: Find current flows in each line of the system using equation (10).
STEP 6: Calculate SCMVA rating of circuit breaker(choose acc. to the fault current magnitude) for each line & at each bus using equation (11).

III. Results And Discussion

3.1 RESULTS FOR IEEE 11 BUS 17 TRANSMISSION LINE SYSTEM

Firstly, discuss the results for load flow for IEEE 11 bus system. The load flow analysis was carried out using the Newton-Raphson load flow method. This analysis determines the voltage magnitude, phase angle in degree, real power and reactive powers at each bus and current flows in the transmission lines. The result of the load flow is shown in Table 1 and Table 2. It can be observed that the voltage magnitudes are within the tolerance ranges of ± 10%.

Table 1: Voltage magnitude , phase Angle, Real and Reactive Powers from pre-fault analysis by Newton Raphson Method on Standard IEEE 11 bus system.

Bus no.	Voltage magnitude (p.u)	Voltage magnitude (KV)	Angle (degree)	Real Power (p.u)	Reactive Power (p.u)
1	1.0700	70.6200	0.0000	0.4339	0.2639
2	1.0924	72.1009	1.6622	0.6625	0.4989
3	1.0950	72.2700	8.5206	0.6625	-0.0504
4	1.0620	70.0920	3.9906	0.4778	0.1539
5	1.0460	69.0360	2.2811	0.4778	0.1461
6	1.0501	69.3068	2.4221	-0.1000	-0.0200
7	1.0118	66.7783	-3.0409	-0.4000	-0.1000
8	0.9890	65.2723	-3.3570	-0.9000	-0.4500
9	0.9983	65.8876	-1.5303	-0.7000	-0.3500
10	1.0326	68.1517	-1.9984	-0.2500	-0.0500
11	1.0310	68.0450	-2.4009	-0.2500	-0.0500

Table 2: Line current magnitudes from load flow analysis using Newton Raphson Method on IEEE 11 bus system.

Line no.	From bus – To bus	CurrentMagnitude (p.u)	Current Magnitude (A)
1	1-9	0.0129	11.2668
2	1-11	0.0099	8.6243
3	2-3	0.0219	19.1902
4	2-7	0.0198	17.3179
5	2-10	0.0152	13.2654
6	3-4	0.0153	13.4033
7	4-6	0.0052	4.5841
8	4-8	0.0252	22.0357
9	4-9	0.0198	17.2849
10	5-6	0.0008	0.7106
11	5-9	0.0139	12.1762
12	7-8	0.0039	3.4424
13	7-10	0.0047	4.0925
14	8-9	0.0055	4.8421
15	8-10	0.0083	7.2988
16	8-11	0.0076	6.6374
17	10-11	0.0012	1.0890

After the pre-fault calculations, a three phase short circuit fault was simulated on the 11 bus system then calculated the total fault current at each bus, fault voltage magnitude at each bus, fault voltage phase angle at each bus, fault current flows in the lines, SCMVA ratings based on the fault currents on each bus and lines was also calculated then the corresponding Circuit Breakers ratings are choosed. Total fault current at each bus and SCMVA ratings for that fault currents on each bus is shown in Table 3. The range of the circuit breakers at each bus determined for the 11 bus system is within 35MVA and 45MVA.

Table 3: Fault current magnitude, Short circuit MVA and Circuit breaker ratings at each bus.

Fault at bus no.	Fault current magnitude(p.u)	Fault current magnitude(A)	SCMVA (MVA)	Circuit Breaker Rating (MVA)
1	0.3741	1963.5	40.0202	45
2	0.3743	1964.5	40.8816	45
3	0.3839	2014.9	42.0314	45
4	0.3601	1890.0	38.2426	40
5	0.3651	1916.2	38.1894	40
6	0.3702	1943.1	38.8747	40
7	0.3448	1809.7	34.8868	35
8	0.3316	1740.4	32.7952	35
9	0.3395	1781.9	33.8922	35
10	0.3500	1837.1	36.1410	40
11	0.3535	1855.3	36.4458	40

Compare the pre-fault voltage magnitude in p.u. and fault voltage magnitude at each bus and it is observed that when a short circuit occurs, the voltage at faulted bus is reduced to zero and voltage magnitude on other buses are also effected, shown in Table 4 and also compare the pre-fault voltage angle in degree with the post-fault angle at each bus. It is seen that voltage angle at each bus increases when fault occur at different buses as shown in Table5.

Table 4: Effect on voltage magnitude in p.u after short circuit occurs at different buses.

Bus no.	Pre-fault Voltage (p.u)	When fault at bus no. 1	When fault at bus no. 2	When fault at bus no. 3	When fault at bus no. 4	When fault at bus no. 5	When fault at bus no. 6	When fault at bus no. 7	When fault at bus no. 8	When fault at bus no. 9	When fault at bus no.10	When fault at bus no.11
1	**1.0700**	0	0.0755	0.1134	0.0371	0.0486	0.0730	0.0236	0.0633	0.0422	0.0124	0.0255
2	**1.0924**	0.0558	0	0.0711	0.0156	0.0419	0.0569	0.0609	0.0884	0.0515	0.0468	0.0238
3	**1.0950**	0.0608	0.0386	0	0.0176	0.0322	0.0386	0.0462	0.0840	0.0578	0.0303	0.0215
4	**1.0620**	0.0886	0.0839	0.0894	0	0.0488	0.0515	0.0165	0.0531	0.0327	0.0162	0.0283
5	**1.0460**	0.0971	0.1090	0.1303	0.0463	0	0.0557	0.0214	0.0333	0.0377	0.0344	0.0411
6	**1.0501**	0.1013	0.1039	0.1164	0.0291	0.0359	0	0.0196	0.0364	0.0267	0.0315	0.0419
7	**1.0118**	0.1299	0.1091	0.1599	0.0902	0.1134	0.1304	0	0.0141	0.0319	0.0369	0.0614
8	**0.9890**	0.1489	0.1454	0.1836	0.1080	0.1295	0.1470	0.0495	0	0.0472	0.0680	0.0810
9	**0.9983**	0.1370	0.1532	0.1782	0.0961	0.0871	0.1215	0.0603	0.0143	0	0.0765	0.0815
10	**1.0326**	0.1062	0.0862	0.1397	0.0710	0.0942	0.1116	0.0071	0.0322	0.0167	0	0.0371
11	**1.0310**	0.0756	0.1078	0.1492	0.0744	0.0910	0.1120	0.0183	0.0287	0.0131	0.0274	0

Table 5: Effect on voltage angle in degree after short circuit occurs at different buses.

Bus no.	Pre-fault Voltage (p.u)	When fault at bus no. 1	When fault at bus no. 2	When fault at bus no. 3	When fault at bus no. 4	When fault at bus no. 5	When fault at bus no. 6	When fault at bus no. 7	When fault at bus no. 8	When fault at bus no. 9	When fault at bus no.10	When fault at bus no.11
1	**0**	0	166.64	164.97	156.93	151.86	154.35	34.24	5.715	13.736	58.96	11.02
2	**1.6622**	153.47	0	161.85	121.56	139.59	144.71	6.7601	3.406	16.942	5.420	39.91
3	**8.5206**	153.47	160.55	0	19.582	130.87	135.24	16.64	5.286	13.519	22.31	60.41
4	**3.9906**	162.79	167.92	167.78	90.00	154.81	154.66	61.242	7.773	19.246	125.36	139.28
5	**2.2811**	165.85	169.05	167.86	167.37	0	160.91	130.04	14.91	4.8034	153.95	153.92
6	**2.4221**	164.77	168.64	167.96	168.20	159.26	0	121.35	14.49	18.781	150.64	151.93
7	**-3.0409**	169.47	174.86	170.69	171.39	166.56	165.52	0	12.08	153.87	171.61	166.52
8	**-3.3570**	171.28	174.47	171.75	173.60	169.16	167.91	169.96	0	165.09	173.20	170.44
9	**-1.5303**	170.98	172.60	171.09	173.49	171.32	168.19	165.21	148.4	-90.00	169.50	168.38
10	**-1.9984**	167.67	174.21	169.35	168.67	163.53	162.78	89.66	7.220	120.80	90.00	159.64
11	**-2.4009**	171.14	171.74	168.90	168.69	164.05	163.08	141.04	9.816	110.24	162.13	0

Table 6: Effect of three phase short circuit fault on line current magnitudes in p.u.

Line no.	Pre-Fault current (p.u)	When fault at bus no. 1	When fault at bus no. 2	When fault at bus no. 3	When fault at bus no. 4	When fault at bus no. 5	When fault at bus no. 6	When fault at bus no. 7	When fault at bus no. 8	When fault at bus no. 9	When fault at bus no.10	When fault at bus no.11
1	**0.0129**	**0.2624**	0.1504	0.1275	0.1178	0.0849	0.1025	0.1491	0.1440	0.0809	0.1565	0.2021
2	**0.0099**	**0.4512**	0.1985	0.2203	0.2315	0.2663	0.2468	0.2014	0.2071	0.2721	0.1940	0.1523
3	**0.0219**	0.0096	0.0740	**0.1363**	0.0495	0.0214	0.0381	0.0331	0.0101	0.0136	0.0381	0.0160
4	**0.0198**	0.2615	**0.3668**	0.3036	0.2724	0.2635	0.2685	0.2048	0.2503	0.2620	0.2797	0.2622
5	**0.0152**	0.3212	**0.5144**	0.4160	0.3667	0.3487	0.3589	0.3605	0.3360	0.3450	0.2794	0.3164
6	**0.0153**	0.1194	0.1812	**0.3534**	0.0695	0.0922	0.0782	0.1437	0.1225	0.1007	0.1480	0.1267
7	**0.0052**	0.0441	0.0676	0.0909	0.0979	0.0448	**0.1731**	0.0615	0.0589	0.0201	0.0613	0.0523
8	**0.0252**	0.2099	0.2114	0.3182	**0.3633**	0.2794	0.3285	0.1918	0.1786	0.2574	0.1961	0.1974
9	**0.0198**	0.0975	0.1340	0.1706	**0.1841**	0.0817	0.1388	0.1270	0.1241	0.0627	0.1261	0.1119
10	**0.0008**	0.0120	0.0134	0.0366	0.0454	0.0946	**0.1468**	0.0095	0.0080	0.0354	0.0090	0.0043
11	**0.0139**	0.2457	0.2681	0.2901	0.2999	**0.5196**	0.3971	0.2657	0.2648	0.2251	0.2648	0.2559
12	**0.0039**	0.1146	0.2171	0.1427	0.1089	0.1014	0.1050	**0.2955**	0.0844	0.1021	0.1854	0.1206
13	**0.0047**	0.0947	0.0904	0.0812	0.0771	0.0787	0.0777	0.0283	0.0716	0.0793	**0.1459**	0.0988
14	**0.0055**	0.0307	0.0241	0.0153	0.0314	0.1122	0.0674	0.0307	0.0376	**0.1244**	0.0257	0.0078
15	**0.0083**	0.1704	0.2341	0.1758	0.1493	0.1457	0.1472	0.1931	0.1272	0.1467	**0.2687**	0.1785
16	**0.0076**	0.2455	0.1283	0.1189	0.1162	0.1335	0.1233	0.1166	0.0966	0.1382	0.1393	**0.2726**
17	**0.0012**	0.0819	0.0578	0.0254	0.0088	0.0089	0.0019	0.0393	0.0098	0.0119	0.0722	**0.0977**

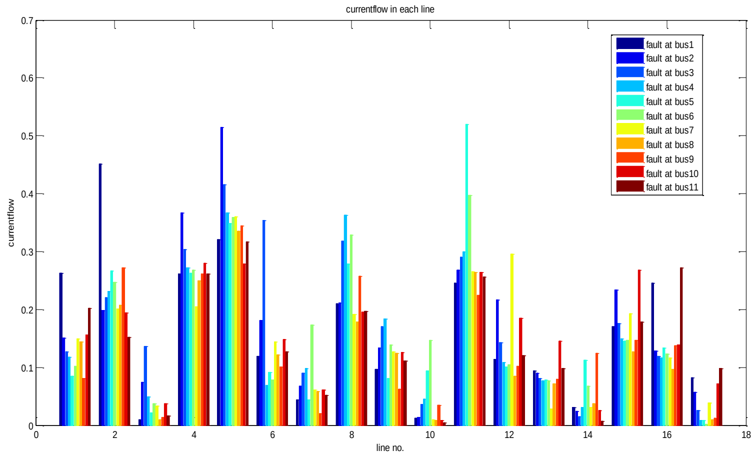

Figure 7: Graphical Representation of line currents when fault occur at different buses.

From the Table 6, it is analyzed that in line no. 1 maximum fault current flowing upto 0.2624 p.u. when there is a fault at bus no.1 & line no. 2 is most effected when there is a fault at bus no.1.& line no.3 is most effected when there is a fault at bus no.3.& similarly check other lines and this effect is clearly shown from graphical representation of current flow in each line when short circuit fault occurs at different buses as shown in Fig.7 Now choose the SCMVA rating of Circuit Breaker for each line according to the Table 6.

Table7: SCMVA and Circuit Breaker Ratings in each line of the Standard 11 bus system.

Line no.	SCMVA	Circuit Breaker rating (MVA)
1	28.07	30
2	48.28	50
3	14.88	20
4	40.07	50
5	56.19	60
6	38.70	40
7	18.37	20
8	38.58	40
9	19.55	20
10	15.35	20
11	54.34	60
12	29.89	30
13	14.76	20
14	12.31	20
15	26.57	30
16	26.95	30
17	10.08	20

3.2 RESULTS FOR IEEE 30 BUS 41 TRANSMISSION LINE SYSTEM

The load flow analysis was carried out using the Newton-Raphson load flow method then after the pre-fault calculations, a three phase short circuit fault was simulated on bus no.1,2,3,4,13,15,16,28,30 of the IEEE 30 bus system then calculated the fault voltage magnitude at each bus, fault voltage angle at each bus, fault currents flows in the lines, total fault current at each bus, SCMVA ratings based on the fault currents on each bus and line then the corresponding Circuit Breakers ratings are choosed. Compare the pre-fault results with post-fault results and all these results are shown below.

Table 8: Effect on voltage magnitude in p.u after short circuit occurs at buses 1,2,3,4,13,15,16,28,30.

Bus no	**Pre-fault voltage (p.u)**	**When Fault at bus 1**	**When Fault at bus 2**	**When Fault at bus 3**	**When Fault at bus 4**	**When Fault at bus 13**	**When Fault at bus 15**	**When Fault at bus 16**	**When Fault at bus 28**	**When Fault at bus 30**
1	**1.0600**	**0**	0.0069	0.0228	0.0333	0.1244	0.0270	0.0520	0.0312	0.2072
2	**1.0450**	0.0243	**0**	0.0101	0.0221	0.1342	0.0321	0.0601	0.0213	0.2127
3	**1.0213**	0.0560	0.0388	**0**	0.0042	0.1537	0.0485	0.0789	0.0094	0.2301
4	**1.0118**	0.0647	0.0452	0.0159	**0**	0.1566	0.0510	0.0816	0.0104	0.2313
5	**1.0100**	0.0648	0.0422	0.0261	0.0123	0.1661	0.0592	0.0895	0.0137	0.2359
6	**1.0027**	0.0740	0.0533	0.0289	0.0138	0.1655	0.0583	0.0885	0.0110	0.2316
7	**0.9970**	0.0794	0.0579	0.0369	0.0222	0.1750	0.0674	0.0978	0.0206	0.2412
8	**0.9989**	0.0784	0.0577	0.0333	0.0182	0.1697	0.0622	0.0925	0.0122	0.2330

9	**1.0012**	0.0755	0.0550	0.0298	0.0146	0.1499	0.0426	0.0678	0.0126	0.2260
10	**0.9778**	0.0989	0.0785	0.0528	0.0375	0.1642	0.0549	0.0784	0.0354	0.2416
11	**1.0465**	0.0304	0.0103	0.0159	0.0308	0.1048	0.0211	0.0290	0.0341	0.1908
12	**1.0113**	0.0653	0.0454	0.0180	0.0025	0.0929	0.0144	0.0387	0.0078	0.2204
13	**1.0468**	0.0300	0.0104	0.0177	0.0330	**0**	0.0394	0.0204	0.0319	0.1934
14	**0.9927**	0.0839	0.0639	0.0367	0.0212	0.1150	0.0129	0.0565	0.0234	0.2334
15	**0.9853**	0.0913	0.0713	0.0443	0.0289	0.1293	**0**	0.0656	0.0297	0.2357
16	**1.0042**	0.0724	0.0523	0.0257	0.0102	0.1158	0.0218	**0**	0.0118	0.2235
17	**0.9698**	0.1068	0.0866	0.0606	0.0452	0.1655	0.0590	0.0702	0.0439	0.2495
18	**0.9697**	0.1069	0.0868	0.0603	0.0449	0.1544	0.0317	0.0825	0.0445	0.2487
19	**0.9638**	0.1128	0.0926	0.0664	0.0510	0.1660	0.0472	0.0894	0.0501	0.2536
20	**0.9665**	0.1101	0.0899	0.0638	0.0485	0.1663	0.0498	0.0875	0.0472	0.2513
21	**0.9648**	0.1119	0.0915	0.0658	0.0505	0.1764	0.0655	0.0917	0.0480	0.2484
22	**0.9655**	0.1112	0.0908	0.0651	0.0498	0.1755	0.0642	0.0912	0.0471	0.2465
23	**0.9683**	0.1084	0.0882	0.0617	0.0464	0.1564	0.0328	0.0860	0.0449	0.2395
24	**0.9546**	0.1221	0.1018	0.0760	0.0607	0.1835	0.0678	0.1048	0.0565	0.2372
25	**0.9587**	0.1183	0.0979	0.0725	0.0573	0.1910	0.0781	0.1129	0.0472	0.1834
26	**0.9399**	0.1371	0.1167	0.0913	0.0761	0.2098	0.0964	0.1313	0.0660	0.1990
27	**0.9703**	0.1069	0.0864	0.0613	0.0461	0.1867	0.0758	0.1091	0.0324	0.1442
28	**0.9971**	0.0804	0.0597	0.0352	0.0201	0.1705	0.0626	0.0932	**0**	0.2226
29	**0.9493**	0.1278	0.1073	0.0823	0.0671	0.2077	0.0961	0.1296	0.0534	0.0791
30	**0.9371**	0.1400	0.1195	0.0945	0.0793	0.2198	0.1081	0.1415	0.0656	**0**

Table 9: Effect on voltage angle (δ) in degree after short circuit occurs at buses 1,2,3,4,13,15,16,28,30.

Bus no	Pre-fault angle (p.u)	When Fault at bus 1	When Fault at bus 2	When Fault at bus 3	When Fault at bus 4	When Fault at bus 13	When Fault at bus 15	When Fault at bus 16	When Fault at bus 28	When Fault at bus 30
1	**0**	**0**	26.2924	12.1461	8.2398	173.8579	117.9386	147.2798	19.5882	138.3340
2	**-3.1269**	173.2652	**0**	25.9681	9.2193	174.9636	135.8308	153.8328	24.4117	140.5312
3	**-5.3230**	174.9046	172.9516	**0**	30.9230	176.1388	153.9415	161.0733	112.3222	144.0999
4	**-6.5336**	175.6930	175.2229	172.6097	**0**	177.1108	158.0571	163.4217	139.2780	145.1933
5	**-6.2187** -	176.2063	177.3193	170.0837	164.7405	176.0970	158.4620	163.2899	145.4304	145.5689
6	**7.5981** -	176.1259	176.2316	173.8492	174.5654	176.9561	160.8206	164.9695	154.9296	146.2358
7	**7.5647**	176.4538	176.9265	174.1297	174.3903	176.7595	162.4887	165.7019	163.1467	147.1720
8	**-8.3064**	176.2130	176.3447	174.3666	175.3501	176.9581	161.9152	165.5149	160.5871	146.7336
9	**-11.0576**	176.2179	176.3264	174.2021	175.3003	175.8868	152.4505	160.9605	157.2314	144.6214
10	**-12.9330**	177.1186	177.4175	176.7831	178.2722	175.8827	158.6868	163.9610	171.9233	146.9071
11	**-11.0576**	170.5841	159.8797	10.8927	2.2186	174.1095	68.9798	130.3110	8.2199	136.7224
12	**-12.4920**	175.7067	175.2945	173.0522	175.5915	179.6619	84.9451	148.5088	123.1889	142.5854
13	**-12.4920**	170.6315	159.0658	7.0595	0.3286	**0**	21.2478	82.9381	11.7752	136.1818
14	**-13.4405**	176.6508	176.6735	176.4706	179.2353	179.1790	134.2166	158.8004	164.3603	145.2144
15	**-13.4436**	176.9104	177.0378	176.8954	179.1007	178.4280	**0**	161.5119	168.5594	145.9758
16	**-12.8307**	176.1020	176.0107	174.3480	176.5934	177.1418	129.1134	**0**	150.3527	143.4787
17	**-13.2607**	177.3407	177.6380	177.3133	178.7578	176.4847	161.0812	167.2227	173.1637	147.9895
18	**-14.0434**	177.3524	177.6015	177.5253	179.1122	177.5751	166.9401	165.1720	172.8175	147.9657
19	**-14.1873**	177.4859	177.7721	177.6493	179.0569	177.1252	165.9771	166.2105	173.8384	148.6608
20	**-13.9364**	177.4217	177.7150	177.4966	178.9161	176.7999	164.0071	165.8182	173.5902	148.3344
21	**-13.4149**	177.4504	177.7767	177.4291	178.7353	176.2831	163.0117	166.2747	174.1993	148.2080
22	**-13.3908**	177.4333	177.7570	177.4049	178.7236	176.3016	162.9376	166.1836	174.1523	148.0283
23	**-13.7252**	177.3750	177.6231	177.5741	179.1300	177.7624	169.0398	165.4858	173.4782	147.6055
24	**-13.7148**	177.6457	177.9598	177.8181	179.0230	177.0489	167.6880	167.5876	175.8841	148.5879
25	**-13.2718**	177.5025	177.8359	177.4776	178.6289	176.4947	165.7799	167.0836	178.3394	144.7342
26	**-13.7455**	177.8449	178.1846	177.9969	178.9677	176.8086	168.5251	168.9184	178.8123	147.8607
27	**-12.6992**	177.1925	177.5203	176.8572	178.0582	176.0698	163.2939	165.8686	-179.678	138.2480
28	**-8.2282**	176.2688	176.4137	174.6060	175.6829	176.9310	162.1233	165.5754	**0**	146.8265
29	**-14.0702**	177.6534	178.0052	177.6589	178.6657	176.4669	166.8935	168.1365	-179.805	140.7209
30	**-15.0579**	177.8578	178.2088	177.9611	178.8709	176.6629	168.3605	169.1519	-179.841	**0**

Table 10: Effect of three phase short circuit fault on line current magnitudes in p.u.

Line no.	From-to	Pre-fault linecurrent (p.u)	When Fault at bus 1	When Fault at bus 2	When Fault at bus 3	When Fault at bus 4	When Fault at bus 13	When Fault at bus 15	When Fault at bus 16	When Fault at bus 28	When Fault at bus 30
1	1-2	**0.0036**	**0.4006**	0.1136	0.2180	0.1842	0.1665	0.1726	0.1699	0.1666	0.1608
2	1-3	**0.0178**	**0.2936**	0.2346	0.1196	0.1546	0.1564	0.1626	0.1624	0.1732	0.1668
3	2-4	**0.0127**	0.2210	**0.2473**	0.1363	0.1210	0.1262	0.1340	0.1341	0.1498	0.1420
4	3-4	**0.0009**	0.2175	0.1650	**0.3951**	0.1040	0.0975	0.1087	0.1068	0.1175	0.1135
5	2-5	**0.0134**	0.2146	**0.2235**	0.1840	0.1781	0.1696	0.1696	0.1684	0.1625	0.1613
6	2-6	**0.0168**	0.2680	**0.2873**	0.2041	0.1921	0.1712	0.1736	0.1707	0.1600	0.1569
7	4-6	**0.0009**	0.2169	0.1894	0.3040	**0.3208**	0.2076	0.1809	0.1670	0.0691	0.0981
8	5-7	**0.0034**	0.1169	0.1257	0.0882	0.0830	0.0730	0.0747	0.0734	0.0690	0.0681
9	6-7	**0.0005**	0.0628	0.0539	0.0921	0.0977	0.1100	0.1073	0.1093	0.1136	0.1194

10	6-8	**0.0006**	0.1013	0.1011	0.1005	0.1003	0.0967	0.0937	0.0953	0.0381	0.0557
11	6-9	**0.0126**	0.0073	0.0082	0.0042	0.0037	0.0764	0.0834	0.1028	0.0079	0.0413
12	6-10	**0.0531**	0.0448	0.0454	0.0431	0.0427	0.0060	0.0072	0.0183	0.0451	0.0187
13	9-11	**0.0094**	0.2178	0.2178	0.2178	0.2178	0.2178	0.2178	0.2178	0.2178	0.2178
14	9-10	**0.0044**	0.2128	0.2138	0.2097	0.2091	0.1300	0.1222	0.1028	0.2133	0.1658
15	4-12	**0.0269**	0.0026	0.0007	0.0085	0.0096	**0.2498**	0.1906	0.1772	0.0142	0.0586
16	12-13	**0.0050**	0.2536	0.2536	0.2536	0.2536	**0.6634**	0.2536	0.2536	0.2536	0.2536
17	12-14	**0.0071**	0.0656	0.0654	0.0660	0.0660	0.0780	0.0402	0.0694	0.0642	0.0588
18	12-15	**0.0045**	0.1781	0.1774	0.1804	0.1809	**0.2494**	0.0981	0.1999	0.1703	0.1397
19	12-16	**0.0020**	0.0324	0.0317	0.0348	0.0353	0.1062	0.0694	**0.1759**	0.0274	0.0211
20	14-15	**0.0022**	0.0136	0.0135	0.0140	0.0141	0.0263	0.0236	0.0174	0.0122	0.0071
21	16-17	**0.3540**	0.1640	0.1632	0.1664	0.1668	0.2368	0.2006	**0.3342**	0.1586	0.1521
22	15-18	**0.0045**	0.0642	0.0638	0.0655	0.0657	0.1038	0.1303	0.0723	0.0619	0.0635
23	18-19	**0.0009**	0.0410	0.0406	0.0423	0.0425	0.0808	0.1078	0.0491	0.0387	0.0403
24	19-20	**0.0004**	0.0354	0.0358	0.0342	0.0339	0.0130	0.0404	0.0274	0.0378	0.0361
25	10-20	**0.0047**	0.0493	0.0497	0.0480	0.0477	0.0148	0.0308	0.0412	0.0517	0.0500
26	10-17	**0.0009**	0.0882	0.0890	0.0858	0.0853	0.0239	0.0523	0.1021	0.0937	0.1003
27	10-21	**0.0013**	0.1576	0.1577	0.1574	0.1573	0.1490	0.1389	0.1657	0.1531	0.1061
28	10-22	**0.0024**	0.0740	0.0740	0.0738	0.0738	0.0684	0.0619	0.0792	0.0710	0.0407
29	21-22	**0.0000**	0.0264	0.0263	0.0267	0.0267	0.0353	0.0465	0.0184	0.0310	0.0797
30	15-23	**0.0040**	0.0757	0.0752	0.0772	0.0775	0.1204	0.1455	0.0933	0.0689	0.0344
31	22-24	**0.0026**	0.0516	0.0517	0.0512	0.0511	0.0393	0.0305	0.0647	0.0446	0.0451
32	23-24	**0.0041**	0.0459	0.0454	0.0474	0.0476	0.0907	0.1164	0.0635	0.0391	0.0157
33	24-25	**0.0032**	0.0102	0.0105	0.0092	0.0090	0.0203	0.0280	0.0215	0.0252	0.1465
34	25-26	**0.0093**	0.0411	0.0411	0.0411	0.0411	0.0411	0.0411	0.0411	0.0411	0.0411
35	25-27	**0.0036**	0.0486	0.0489	0.0476	0.0474	0.0193	0.0171	0.0188	0.0632	0.1838
36	28-27	**0.0322**	0.0719	0.0723	0.0708	0.0706	0.0446	0.0360	0.0431	0.0877	**0.2246**
37	27-29	**0.0146**	0.0447	0.0447	0.0447	0.0447	0.0447	0.0447	0.0447	0.0447	0.1387
38	27-30	**0.0351**	0.0486	0.0486	0.0486	0.0486	0.0486	0.0486	0.0486	0.0486	**0.2112**
39	29-30	**0.0104**	0.0238	0.0238	0.0238	0.0238	0.0238	0.0238	0.0238	0.0238	**0.1543**
40	8-28	**0.0005**	0.0094	0.0095	0.0092	0.0091	0.0036	0.0021	0.0033	0.0582	0.0497
41	6-28	**0.0008**	0.1029	0.1029	0.1015	0.1011	0.0800	0.0728	0.0780	**0.1769**	0.1505

From table 10, Comparing the line flow currents during fault with the pre-fault line flow currents; it is analyze that line currents increases from their normal value when there is a fault at different buses. Above table also shows that how much fault current flows in each line when there is a fault at different buses. From Table 10, in line no. 1 maximum current flowing when there is a fault occur at bus no.1 i.e 0.4006 p.u & in line no. 2 maximum current flowing when there is a fault at bus no.1.& in line no.3 maximum current flowing during fault at bus no.2 & in line no. 4 maximum current flowing when there is a fault at bus no.3 & similarly check other lines for fault at each bus of the system and choose the SCMVA rating of CB for each line acc. to above table. This effect is cleared by a graph that showing the current flow in line no.1 when fault occur at different buses, as shown in fig.8.

From Table 11&12, it is to be noted that in the lines of IEEE 30bus 330KV system , circuit breaker ratings ranges between 10 MVA to 70 MVA. The operating personnel can use the relay settings according to the fault current magnitude & circuit breaker ratings.

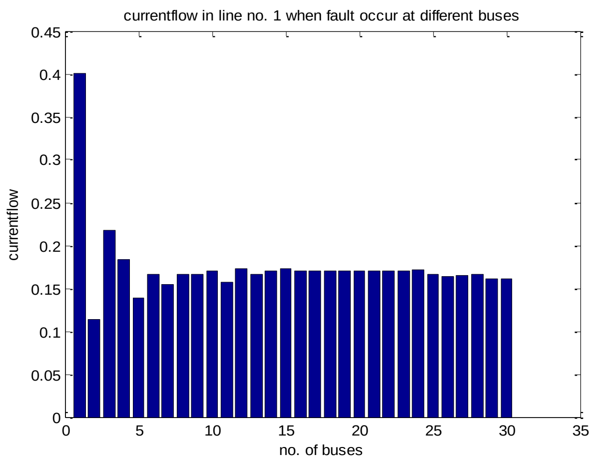

Figure 8: Graphical Representation for Current flow in line no.1 when there is a fault occur at each bus of Ieee 30 bus system.

Table11&12 SCMVA and Circuit Breaker Ratings in each line of the Ieee 30 bus system.

Line no.	SCMVA	CB Ratings	Line no.	SCMVA	CB Ratings
1	42.46	45	22	15.41	20
2	31.11	35	23	19.74	20
3	25.84	30	24	18.50	20
4	40.34	45	25	20.36	25
5	23.35	25	26	18.61	20
6	30.02	35	27	18.23	20
7	32.45	35	28	9.076	15
8	26.83	30	29	18.75	20
9	18.33	20	30	15.13	20
10	21.08	25	31	14.02	20
11	21.68	25	32	19.62	20
12	4.841	10	33	21.04	25
13	63.58	65	34	38.52	40
14	37.78	40	35	18.22	20
15	25.27	30	36	22.38	30
16	67.08	70	37	25.62	30
17	20.89	25	38	20.49	25
18	25.22	30	39	14.64	20
19	17.78	20	40	5.919	10
20	14.09	20	41	17.78	20
21	33.55	35			

Table 13&14: Total fault current at each bus and SCMVA ratings for that fault currents on each bus.

When fault at bus no.	Fault current (p.u)	SCMVA	When fault at bus no.	Fault current (p.u)	SCMVA
1	0.3727	39.5029	16	0.3822	38.3842
2	0.3673	38.3869	17	0.3639	35.2884
3	0.3591	36.6706	18	0.3768	36.5398
4	0.3556	35.9829	19	0.3739	36.0412
5	0.3642	36.7819	20	0.3725	36.0029
6	0.3533	35.4265	21	0.3602	34.7527
7	0.3569	35.5856	22	0.3606	34.8131
8	0.3561	35.5680	23	0.3751	36.3251
9	0.3687	36.9123	24	0.3631	34.6653
10	0.3602	35.2240	25	0.3784	36.2744
11	0.4173	43.6731	26	0.4308	40.4867
12	0.3753	37.9588	27	0.3793	36.8030
13	0.4098	42.8995	28	0.3565	35.5490
14	0.3918	38.8945	29	0.4183	39.7060
15	0.3714	36.5971	30	0.4230	39.6398

IV. CONCLUSION

From above results, it is seen that during short circuit fault voltage magnitude at faulty buses reduced to zero and current flow in the lines increases. In IEEE 11 bus system, line no. 11 is most effected i.e. in line no.11 maximum fault current flows during fault at bus no.5 and in IEEE 30 bus system, line no. 16 is most effected when there is a fault occur at bus no.13. So according to the values of fault current flows in the lines, circuit breaker rating is choosen. It is concluded that in the lines of 11 bus system circuit breaker rating ranges within 20 MVA and 60MVA and in the lines of 30 bus system circuit breaker rating ranges within 10 MVA and 70 MVA. As could be observed from the results of this study, the regular calculation of the currents which flow in the power system when a three phase fault symmetrical fault occurs and the selection of appropriate circuit breaker are required for the proper operation of the power system.

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APPENDIX

TEST SYSTEM DATA

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

Table 15: 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 16: 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 17: Line data for standard IEEE 30 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 18: Load data for standard IEEE 30 bus system

Bus no.	Generation (p.u.)		Load (p.u.)		Bus Voltage	
	P_g	Q_g	P_d	Q_d	V (p.u)	δ (deg)
1	1.3848	-0.029	0.000	0.000	1.060	0.0
2	0.400	0.5	0.217	0.127	1.045	0.0
3	0.000	0.000	0.024	0.012	1.000	0.0
4	0.000	0.000	0.076	0.016	1.060	0.0
5	0.000	0.37	0.942	0.19	1.010	0.0
6	0.000	0.000	0.000	0.000	1.000	0.0
7	0.000	0.000	0.228	0.109	1.000	0.0
8	0.000	0.373	0.3	0.3	1.010	0.0
9	0.000	0.000	0.000	0.000	1.000	0.0
10	0.000	0.000	0.058	0.02	1.000	0.0
11	0.000	0.162	0.000	0.000	1.082	0.0
12	0.000	0.000	0.112	0.075	1.000	0.0
13	0.000	0.106	0.000	0.000	1.071	0.0
14	0.000	0.000	0.062	0.016	1.000	0.0
15	0.000	0.000	0.082	0.025	1.000	0.0
16	0.000	0.000	0.035	0.018	1.000	0.0
17	0.000	0.000	0.09	0.058	1.000	0.0
18	0.000	0.000	0.032	0.009	1.000	0.0
19	0.000	0.000	0.095	0.034	1.000	0.0
20	0.000	0.000	0.022	0.007	1.000	0.0
21	0.000	0.000	0.175	0.112	1.000	0.0
22	0.000	0.000	0.000	0.000	1.000	0.0
23	0.000	0.000	0.032	0.016	1.000	0.0
24	0.000	0.000	0.087	0.067	1.000	0.0
25	0.000	0.000	0.000	0.000	1.000	0.0
26	0.000	0.000	0.035	0.023	1.000	0.0
27	0.000	0.000	0.000	0.000	1.000	0.0
28	0.000	0.000	0.000	0.000	1.000	0.0
29	0.000	0.000	0.024	0.009	1.000	0.0
30	0.000	0.000	0.106	0.019	1.000	0.0

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