Unsymmetrical Fault Analysis of 5-Bus Power System Using PowerWorld Simulator

Dr. Aung Zaw Latt

Department of Electrical Power Engineering, Technological University (Maubin), Maubin, Myanmar
aungzawlatt047@gmail.com

Abstract: *The almost all of faults on the power system are unsymmetrical nature. When a fault occur in the power system, it gives rise to the magnitude of currents in the three phase lines are diverse having not the same phase displacement. These unsymmetrical fault currents flow in the system network which causes the damage to equipments and devices. Therefore, the unsymmetrical fault analysis is required to settle on fault currents and voltages for the power system planning, protection equipment selection, and overall system reliability assessment. In this paper, PowerWorld Simulator tool is employed to analyze the unsymmetrical fault of 5-bus power system model. The main objective of fault analysis is to determine fault current distribution and bus voltage levels during unsymmetrical fault conditions in order to give information for the selection of protective equipments to ensure the safe and reliable operation of the system network.*

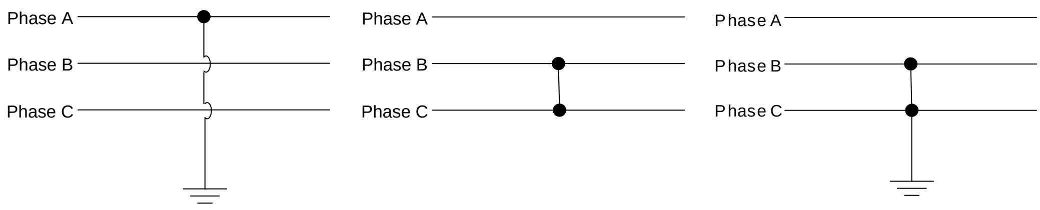
Key Words: *fault analysis, unsymmetrical fault, fault current, bus voltage, PowerWorld Simulator.*

1. INTRODUCTION:

At the heart of today power generation and distribution are high voltage transmission and distribution networks. When a fault occurs at some point in the network, the normal operating conditions of the system are upset; the excessively high currents flow in the system which causes the damage to equipments and the destruction to a power system network. Therefore, the fault analysis is required in power system planning, protection equipment selection, and overall system reliability assessment. In a power system network, the unsymmetrical faults are frequently occurred due to insulation failure, flashover, physical damage or human error and it may also be caused by either short-circuits to earth or between line conductors, or may be caused by broken conductors in one or more phases. These faults may either be three phase in nature involving all three phases in a symmetrical manner, or may be unsymmetrical where usually only one or two phases may be involved. The symmetrical fault may be analysed using an equivalent single phase circuit. Although the fault may be unsymmetrical, the use of symmetrical components help to reduce the complexity of the calculations as transmission lines and components are by and large symmetrical. Generally, fault analysis is calculated in per-unit quantities as they give solutions which are somewhat consistent over different voltage and power ratings, and operate on values of the order of unity. The powerworld simulator tool can be employed to analyse the fault current distribution and bus voltages levels during unsymmetrical fault condition and allows for the easy simulation of bus systems. In this paper, the powerworld simulator tool is employed to analysis the unsymmetrical fault of 5-bus power system model. Although this system model is a relatively small and simple power system, this system works will assist students in understanding fault analysis. The results of changes to the system can be seen quickly in PowerWorld, further aiding students' learning process and utility engineers.

A. Unsymmetrical Fault on 3-Phase System

On the occurrence of an unsymmetrical fault, the currents in the the phase lines becomes unequal and so is the phase displacement among them. It may be well-known that the term unsymmetry applies only to the fault itself and the resulting line currents. The unsymmetrical faults normally considered are (a) line to ground fault, (b) line to line fault, and (c) double line to ground fault.



(a) L-G faut (b) L-L fault (c)L-L-G fault

Fig. 1 Types of unsymmetrical fault on 3 phase system

B. Sequence Impedances of Power System Elements

The concept of impedances of various elements of power system to positive, negative and zero sequence currents is of considerable importance in determining the fault currents in a three phase unbalanced system. The following three main pieces of equipment will be considered: (1) synchronous generators, (2) transformers and (3) Transmission lines.

(1) Synchronous generator: The positive, negative and zero sequence impedances of synchronous generators are normally different. The positive sequence impedance of synchronous generator is equal to the synchronous impedance of the machine. The positive sequence impedance is much greater than the negative sequence impedance. The zero sequence impedance is a variable item and this zero sequence impedance may be assumed to be equal to the positive sequence impedance if its value is not given,. In short:

Negative sequence impedance < Positive sequence impedance

Zero sequence impedance = Variable item

= may be taken equal to the positive sequence impedance if its value is not given

It may be worthwhile to mention here that any impedance Z_e in the earth connection of a star connected system has the effect to introduce an impedance of $3Z_e$ par phase. It is because the three equal zero sequence currents, being in phase, do not sum to zero at the star point, but they flow back along the neutral earth connection.

(2) Transformers: The positive and negative sequence impedances of transformer are equal because of it has the same impedance with reversed phase rotation; this values being equal to the impedance of transformer. But, the zero sequence impedance depends upon the connection of earth. This zero sequence impedance values will be equal to positive sequence impedance if there is a through circuit for earth current; otherwise the zero sequence impedance will be infinite. In short,

Positive sequence impedance = Negative sequence impedance

= Impedance of transformer

Zero sequence impedance = Positive sequence impedance (there is circuit for earth current)

= Infinite, (there is no through circuit for earth current)

(iii) Transmission lines : The positive and negative sequence impedance of a transmission line are the same values; this value is equal to the normal impedance of the line. This is likely because the phase rotation of the currents does not compose any difference in the constants of the transmission line. But, the positive or negative sequence impedance is usually much smaller than the zero sequence impedance. In short,

Positive sequence impedance = Negative sequence impedance

= Impedance of the line

Zero sequence impedance =Variable item

= the three times of the positive sequence impedance if its value is not given

C. Assumptions Commonly Made in 3-Phase Fault Studies

The assumptions are usually made in the fault analysis of three phase transmission lines. These are (1) all generator sources are balanced and equal in magnitude and phase angle, (2) generator sources are expressed by the Thevenin's voltage prior to fault at the fault point, (3) the large system network may be described by an infinite bus-bars, (4) the tap position of transformers are nominal, (5) resistances are negligible in comparison with reactances, (5) transmission lines are assumed all three phases have the same impedances, (6) loads currents are negligible in comparison with fault currents and (7) the currents of line charging can be completely neglected.

D. Description of Per Unit Quantities

In the analysis of power system networks, instead of using actual values it is usual to express them as fractions of reference values. These fractions values are called per unit (p.u). The p.u. value is defined as

$$\frac{\text{actual value (in any unit)}}{\text{base or reference value in the same unit}} \quad (1)$$

Some the system describe the p.u. value as a percentage. By the use of p.u. values, it gives the great advantages such as (1) the apparatus measured may vary extensively in size; volt drops and losses will also vary significantly (2) it can be reduced the use of $\sqrt{3}$ in three-phase calculations , (3) by the selection of suitable voltage bases the solution of the power system networks which contain a number of transformers is facilitated, and (4) the per unit values lend themselves more readily to digital computation.

2. Unsymmetrical Fault Analysis Results using PowerWorld Simulator:

A. Input Data of 5- Bus Power System

Fig. 2 shows single line diagram of 5-bus power system model. As shown in Fig. 2, bus 1, to which a generator is connected, is the slack bus. Bus 2, to which generator is connected, is generator bus. The connected load is 250 MW, 80 MVAR (inductive) at bus 3. Input data for the Simulator include machine, transmission line, and transformer data, as illustrated in Tables I, II, and III as well as the prefault voltage $V_F = 1.0\angle 0$ H and fault impedance $Z_F = 0$.

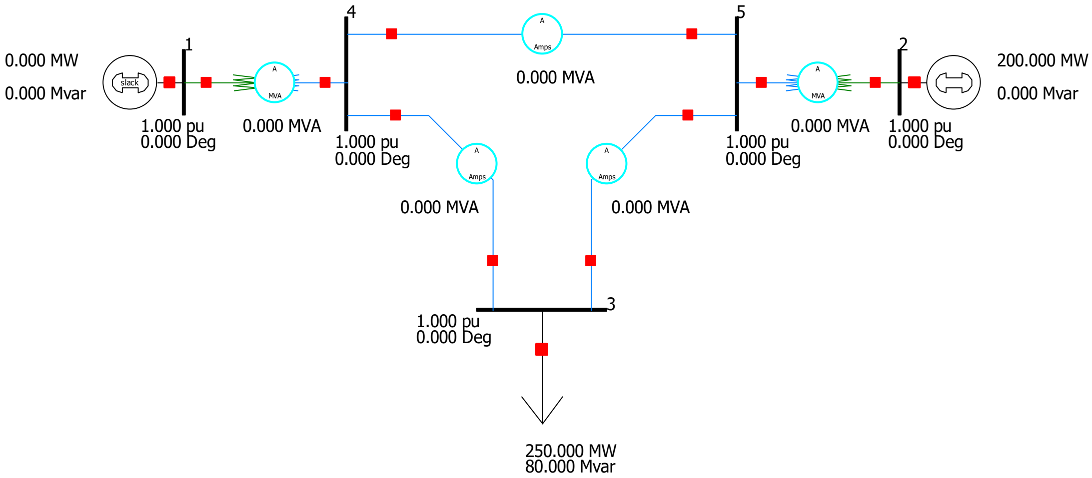


Fig. 2 Test model of 5-bus power system model using PowerWorld simulator

Table I
Synchronous generator input data of 5- bus power system model

Bus	Type	V p.u	δ Degrees	P_G p.u	Q_G p.u	P_L p.u	Q_L p.u	X_1 p.u	X_2 p.u	X_0 p.u	X_n p.u
1	Slack	1	0	-	-	0	0	0.2	0.15	0.05	0.03
2	Generator	1	0	2	-	0	0	0.2	0.15	0.05	0.03

(* S_{base} = 100 MVA , * P_{base} = 100 MW)

Table II
Line input data of 5-bus power system model

Bus to Bus	X_1 (p.u)	X_0 (p.u)	Max MVA (p.u)
3 – 4	0.1	0.3	3
3 – 5	0.1	0.3	3
4 – 5	0.1	0.3	3

Table III
Transformer input data of 5- bus power system model

Low voltage (connection)bus	High voltage (connection)bus	Maximum MVA (p.u)	Off nominal turn Ratio	Phase shift degrees	$X_1 = X_2 = X_0$	Norminal kV
1 (Δ)	4 (Yground)	3	1.0	0	0.05	25/230
2(Δ)	5 (Yground)	3	1.0	0	0.05	13.8/230

B. Unsymmetrical Fault Analysis Results of 5-bus power system

After unsymmetrical fault type is selected in fault analysis dialog at run mode condition, the unsymmetrical fault is calculated consist of the fault current in each phase, contributions to the fault current from each branch connected to the fault bus for each phase and the voltages for a fault at bus 1, bus 2, bus 3, bus 4 and then bus 5. The unsymmetrical fault analysis results are shown in Table IV,V, VI, VII, VIII and IX.

Table IV
Branches results data of 5- bus power system model (L-G Fault)

Fault Bus	Subtransient Current (Phase A)		Fault Current				
			Gen, Line or Xmer	Bus to Bus	Phase A	Phase B	Phase C
	p.u	Degree			p.u	p.u	p.u
1	8.652	-85.11	Gen 1	GRND-1	7.01393	1.25035	0.70217
			Gen 2	GRND-2	2.76313	1.56706	2.86542
			Xmer	1-4	1.6384	1.25035	0.70217
			Xmer	2-5	2.76313	1.56706	2.86542
			Line	4-3	0.59423	1.2541	0.70462
			Line	5-3	1.41537	1.36755	1.75186
			Line	4-5	1.41092	0.37951	1.13338
2	8.652	-77.48	Gen 1	GRND-1	2.30804	1.09565	1.59878
			Gen 2	GRND-2	7.44854	2.722	0.94907
			Xmer	1-4	2.30804	1.09565	1.59878
			Xmer	2-5	1.97024	2.722	0.94907
			Line	4-3	1.15482	0.92076	1.35544
			Line	5-3	0.92297	1.70804	1.13376
			Line	4-5	1.32509	1.10051	0.28905
3	5.484	-86.40	Gen 1	GRND-1	2.05457	0.83471	1.54054
			Gen 2	GRND-2	2.52983	1.51257	2.78972
			Xmer	1-4	2.05457	0.83471	1.54054
			Xmer	2-5	2.52983	1.51257	2.78973
			Line	4-3	2.69235	0.89665	1.3071
			Line	5-3	3.4032	1.83001	1.10993
			Line	4-5	0.80794	1.10402	0.30674
4	6.242	-85.48	Gen 1	GRND-1	2.68584	1.13299	1.79099
			Gen 2	GRND-2	2.68935	1.56758	2.82947
			Xmer	1-4	2.68584	1.13299	1.79099
			Xmer	2-5	2.68935	1.56758	2.82947
			Line	4-3	1.09412	0.88536	1.41722
			Line	5-3	1.9587	1.88002	1.06481
			Line	4-5	2.65407	1.27483	0.40277
5	10.846	-77.82	Gen 1	GRND-1	3.27595	1.43654	2.06065
			Gen 2	GRND-2	4.56967	1.46214	3.8367
			Xmer	1-4	3.27595	1.43654	2.06065
			Xmer	2-5	4.56967	1.46214	3.8367
			Line	4-3	1.2329	0.73509	1.46547
			Line	5-3	1.00721	1.87089	0.8714
			Line	4-5	2.08642	1.49719	0.596

Table V
Bus results data of 5- bus power system model (L-G Fault)

$V_{prefault}$ =1.0 ∠0 H		Bus Voltages during Fault (L-G)		
Fault Bus	Bus	Phase A	Phase B	Phase C
1	1	0.00000	1.0476	0.9808
	2	0.74241	0.94498	0.8714
	3	0.52095	0.81984	0.76346
	4	0.48565	0.84949	0.80483
	5	0.61876	0.88704	0.8162
2	1	0.71987	0.90836	0.89292
	2	0.00000	1.0476	0.9808
	3	0.51061	0.79373	0.78377
	4	0.60551	0.85708	0.84325
	5	0.47642	0.82747	0.81692
3	1	0.76543	0.95759	0.89182
	2	0.78272	0.97524	0.88416
	3	0.00000	1.11977	0.93006
	4	0.39006	1.06521	0.96215
	5	0.57831	0.96342	0.86777
4	1	0.65445	0.91475	0.87542
	2	0.76136	0.95618	0.88523
	3	0.24028	1.03096	0.88453
	4	0.00000	1.17117	1.07133
	5	0.54006	0.94634	0.87534
5	1	0.55004	0.87411	0.84293
	2	0.40597	0.87199	0.79511
	3	0.10072	0.86544	0.73258
	4	0.20864	0.91722	0.81767
	5	0.00000	0.86586	0.78391

Table VI
Branches results data of 5- bus power system model (L-L Fault)

Fault Bus	Subtransient Current (Phase B & C)		Fault Current				
			Gen, Line or Xmer	Bus to Bus	Phase A	Phase B	Phase C
	p.u	Degree			p.u	p.u	p.u
1	8.343	-171.82	Gen 1	Grand-1	0.58306	5.76451	5.41889
	8.343	8.18	Gen 2	Grand-2	2.11781	3.96099	2.5008
			Xmer	1-4	0.58306	2.67613	2.92709
			Xmer	2-5	2.11781	3.96099	2.5008
			Line	4-3	1.05684	0.47918	1.34962
			Line	5-3	1.58071	1.75277	1.02479
			Line	4-5	0.54989	2.21073	1.72845
2	8.343	-164.18	Gen 1	Grand-1	0.86657	3.12587	2.79258
	8.343	15.82	Gen 2	Grand-2	1.97787	6.80923	5.19386
			Xmer	1-4	0.86657	3.12587	2.79258
			Xmer	2-5	1.97787	1.62404	3.5914
			Line	4-3	1.12299	1.54276	0.8706
			Line	5-3	1.52144	0.04753	1.56775
			Line	4-5	0.52131	1.58321	2.09051
3	6.106	-165.08	Gen 1	Grand-1	0.75726	3.22421	2.80466
	6.106	14.92	Gen 2	Grand-2	2.09923	4.10857	2.55986

			Xmer	1-4	0.75726	3.22421	2.80466
			Xmer	2-5	2.09923	4.10857	2.55986
			Line	4-3	1.13285	3.46255	2.61926
			Line	5-3	1.60035	3.76176	2.53432
			Line	4-5	0.53286	0.53286	0.53286
4	7.7	-168.57	Gen 1	Grand-1	0.67808	4.52383	4.16541
	7.7	11.43	Gen 2	Grand-2	2.09417	4.43762	2.87164
			Xmer	1-4	0.67808	4.52383	4.16541
			Xmer	2-5	2.09417	4.43762	2.87164
			Line	4-3	1.08957	0.81175	1.54039
			Line	5-3	1.57979	1.86326	0.96415
			Line	4-5	0.53908	2.5892	2.09284
5	7.672	-165.41	Gen 1	Grand-1	0.7839	3.55251	3.18995
	7.672	14.59	Gen 2	Grand-2	2.04087	5.48439	3.87345
			Xmer	1-4	0.7839	3.55251	3.18995
			Xmer	2-5	2.04087	5.48439	3.87345
			Line	4-3	1.11455	1.63277	0.84241
			Line	5-3	1.55749	0.33201	1.79788
			Line	4-5	0.52717	1.92336	2.44835

Table VII
Bus results data of 5- bus power system model (L-L Fault)

$V_{prefault}$ =1.0 ∠0 H		Bus Voltages during Fault (L-L)		
Fault Bus	Bus	Phase A	Phase B	Phase C
1	1	0.89875	0.44938	0.44938
	2	0.92802	0.60156	0.74261
	3	0.83113	0.41366	0.52416
	4	0.87652	0.42339	0.49375
	5	0.88474	0.47856	0.62246
2	1	0.92119	0.64595	0.65448
	2	0.89875	0.44938	0.44938
	3	0.8282	0.47448	0.45333
	4	0.88363	0.54396	0.5394
	5	0.87132	0.47081	0.43805
3	1	0.94237	0.61398	0.68765
	2	0.94573	0.59174	0.73725
	3	0.85922	0.42961	0.42961
	4	0.91141	0.49741	0.5916
	5	0.90929	0.47527	0.6168
4	1	0.91646	0.49526	0.5183
	2	0.9294	0.54047	0.69368
	3	0.83987	0.39403	0.47096
	4	0.88903	0.44451	0.44451
	5	0.89072	0.4292	0.56733
5	1	0.92479	0.58854	0.616
	2	0.91868	0.4563	0.56681
	3	0.83885	0.42982	0.43404
	4	0.89171	0.48655	0.50635
	5	0.88585	0.44292	0.44292

Table VIII
Branches results data of 5- bus power system model (L-L-G Fault)

Fault Bus	Subtransient Current (Phase B & C)		Fault Current				
	p.u	Degree	Gen, Line or Xmer	Bus to Bus	Phase A p.u	Phase B p.u	Phase C p.u
1	8.576	164.40	Gen 1	Grand-1	0.51898	6.3286	6.33549
	9.160	31.15	Gen 2	Grand-2	2.25491	3.76756	2.76283
			Xmer	1-4	0.51898	2.63754	2.89991
			Xmer	2-5	2.25491	3.76756	2.76283
			Line	4-3	0.71431	0.50405	1.20921
			Line	5-3	1.45441	1.633	1.09702
			Line	4-5	0.82589	2.13485	1.82873
2	8.576	172.03	Gen 1	Grand-1	1.44531	3.06573	2.88995
	9.160	38.79	Gen 2	Grand-2	1.66507	6.75592	6.82186
			Xmer	1-4	1.44531	3.06573	2.88995
			Xmer	2-5	1.66507	1.83823	3.34685
			Line	4-3	1.07204	1.44186	0.9654
			Line	5-3	1.17351	0.26912	1.37181
			Line	4-5	0.76403	1.62991	2.04569
3	5.780	175.31	Gen 1	Grand-1	1.13518	3.10019	2.93547
	6.959	31.91	Gen 2	Grand-2	2.06756	3.90019	2.804
			Xmer	1-4	1.13518	3.10019	2.93547
			Xmer	2-5	2.06756	3.9002	2.804
			Line	4-3	0.97825	3.3146	3.01978
			Line	5-3	1.31117	3.52963	3.37818
			Line	4-5	0.73955	0.21946	0.9463
4	7.556	175.07	Gen 1	Grand-1	1.27574	4.39865	4.23222
	8.261	27.00	Gen 2	Grand-2	2.16034	4.27111	3.06694
			Xmer	1-4	1.27574	4.39864	4.23221
			Xmer	2-5	2.16034	4.27111	3.06694
			Line	4-3	1.05313	0.69778	1.57459
			Line	5-3	1.31774	1.76682	1.48527
			Line	4-5	0.7569	2.46398	2.77797
5	9.291	151.95	Gen 1	Grand-1	2.19539	3.42671	3.41714
	10.263	53.98	Gen 2	Grand-2	3.14905	5.0027	4.44048
			Xmer	1-4	2.19539	3.42671	3.41714
			Xmer	2-5	3.14905	5.0027	4.44048
			Line	4-3	1.03836	1.40518	1.06669
			Line	5-3	0.93994	0.63966	1.42204
			Line	4-5	1.3317	2.02515	2.38991

Table IX

Bus results data of 5- bus power system model (L-L-G Fault)

$V_{prefault}$ =1.0 ∠0 H		Bus Voltages during Fault (L-L-G)		
Fault Bus	Bus	Phase A	Phase B	Phase C
1	1	0.98802	0.00000	0.00000
	2	0.82571	0.58437	0.687
	3	0.67492	0.35778	0.44508
	4	0.6834	0.33822	0.39649
	5	0.74712	0.4422	0.55127
2	1	0.80919	0.60732	0.60655
	2	0.98802	0.00000	0.00000
	3	0.6675	0.40511	0.37928
	4	0.73888	0.48762	0.47547
	5	0.6756	0.37902	0.34285
3	1	0.85764	0.59629	0.64008
	2	0.86839	0.58432	0.68921
	3	1.03823	0.00000	0.00000
	4	1.00815	0.35238	0.3611
	5	0.87117	0.41148	0.49249
4	1	0.79656	0.44587	0.45779
	2	0.84744	0.52408	0.64816
	3	0.93347	0.13035	0.21531
	4	1.10055	0.00000	0.00000
	5	0.85344	0.33706	0.44144
5	1	0.66301	0.50078	0.49761
	2	0.57319	0.33461	0.38959
	3	0.67437	0.06397	0.1422
	4	0.7668	0.20251	0.23899
	5	0.64267	0.00000	0.00000

3. Conclusion

Normally, only 5% of the initial faults in a power system are three phase faults with or without earth. Of the unsymmetrical faults, 80 % are line-ground and 15% are double line faults with or without earth and which can often deteriorate to 3 phase fault.

This paper described unsymmetrical fault analysis of 5-bus power system model using software tool, PowerWorld Simulator. The simulator tool greatly enhances the electrical engineering student's ability and utility engineers to visualize fault current distribution and bus voltage levels during fault conditions in order to provide information for the selection and coordination of protective equipment to ensure the safe and reliable operation of the system.

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Appendix

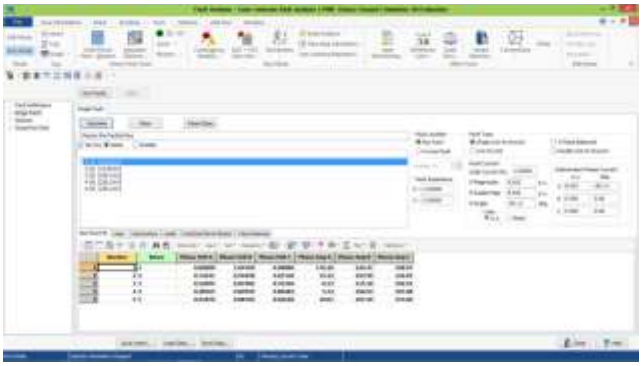
Fig. 1(a)Bus record at Bus 1 (L-G Fault)

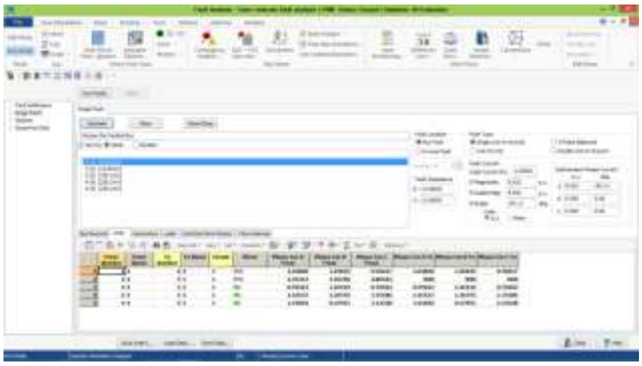
Fig.1(b) branches records at Bus 1 (L-G Fault)

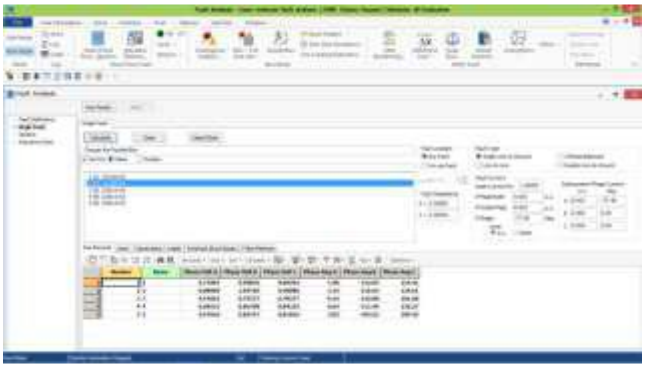
Fig. 2(a) Bus record at Bus 2 (L-G Fault)


Fig. 2(b) branches records at Bus 2 (L-G Fault)

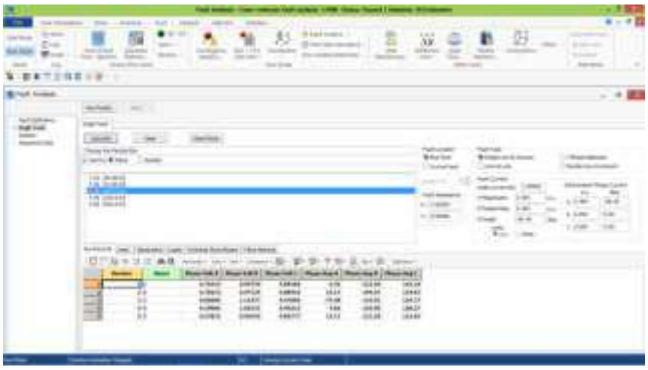
Fig. 3(a) Bus record at Bus 3 (L-G Fault)


Fig. 3(b) branches records at Bus 3 (L-G Fault)


Fig. 4(a) Bus record at Bus 4 (L-G Fault)

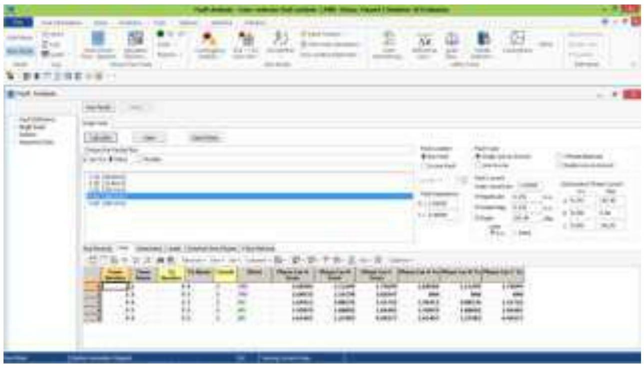
Fig. 4(b) branches records at Bus 4 (L-G Fault)

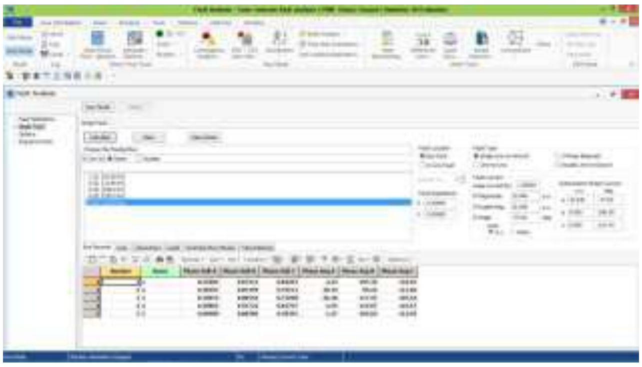
Fig. 5(a) Bus record at Bus 5 (L-G Fault)

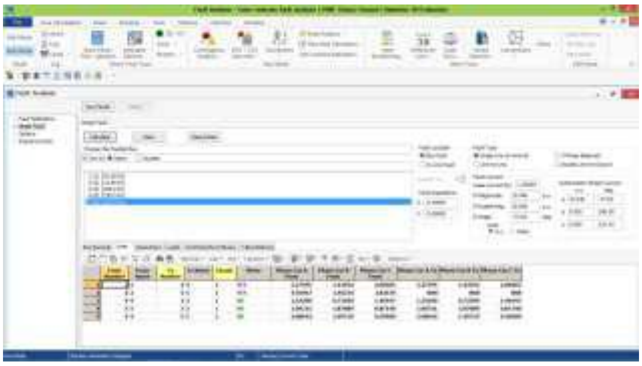
Fig. 5(b) branches records at Bus 5 (L-G Fault)

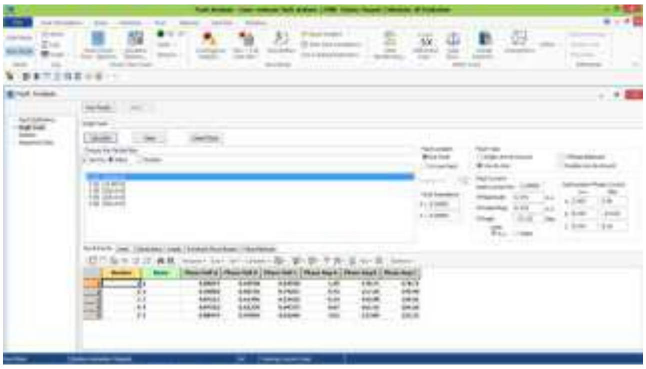
Fig. 6(a) Bus record at Bus 1 (L-L Fault)

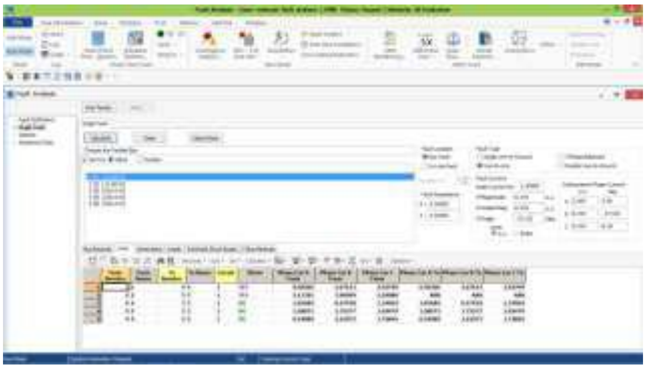
Fig. 6(b) branches records at Bus 1 (L-L Fault)

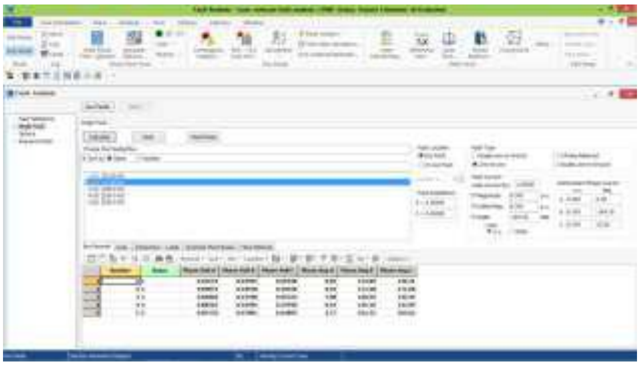
Fig. 7(a) Bus record at Bus 2 (L-L Fault)

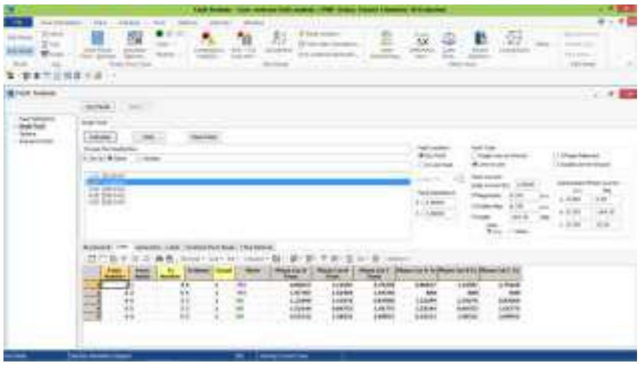
Fig. 7(b) branches records at Bus 2 (L-L Fault)


Fig. 8(a) Bus record at Bus 3 (L-L Fault)


Fig. 8(b) branches records at Bus 3 (L-L Fault)

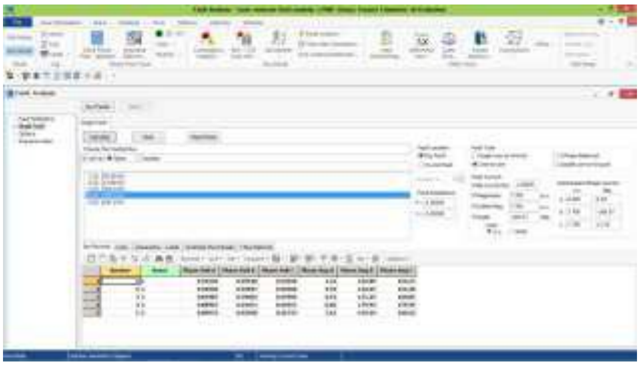

Fig. 9(a) Bus record at Bus 4 (L-L Fault)

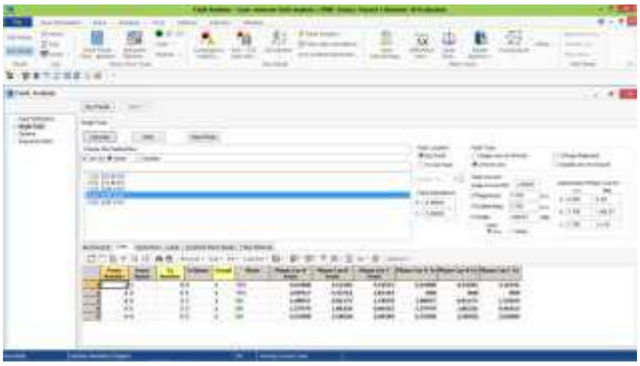

Fig. 9(b) branches records at Bus 4 (L-L Fault)

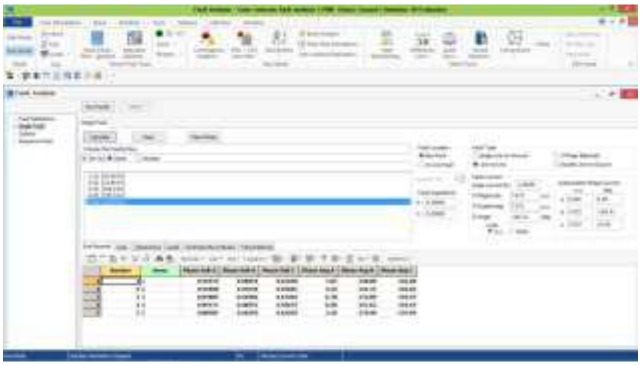

Fig. 10(a) Bus record at Bus 5 (L-L Fault)

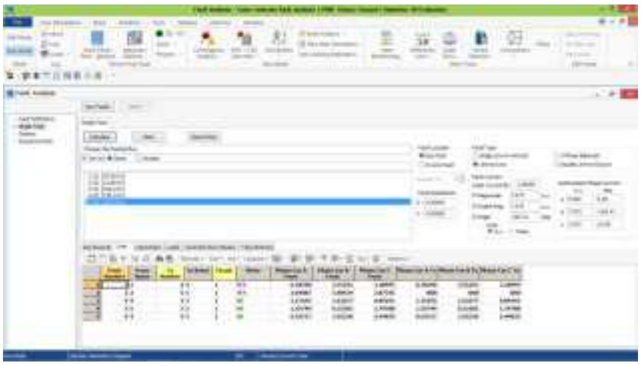

Fig. 10(b) branches records at Bus 5 (L-L Fault)

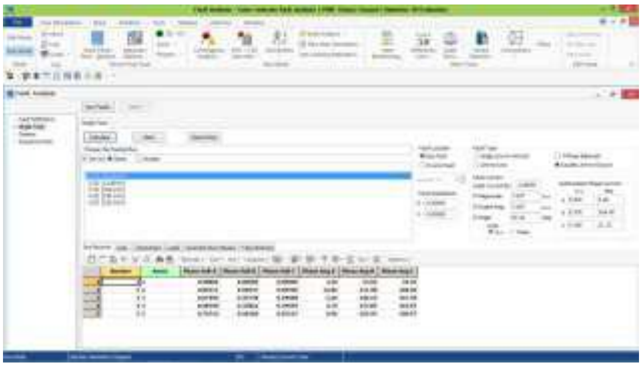

Fig. 11(a) Bus record at Bus 1 (L-L-G Fault)

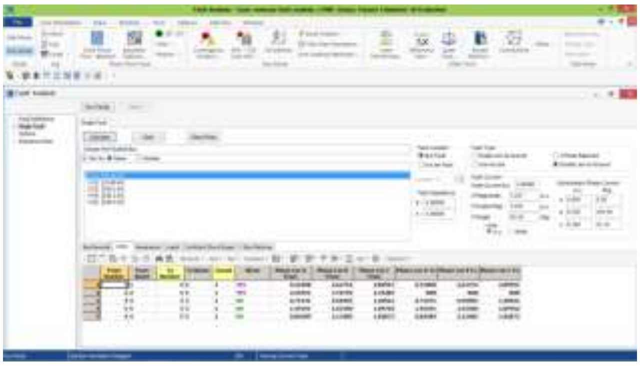

Fig. 11(b) branches records at Bus 1 (L-L-G Fault)

Fig. 12(a) Bus record at Bus 2 (L-L-G Fault)

Fig. 12(b) branches records at Bus 2 (L-L-G Fault)

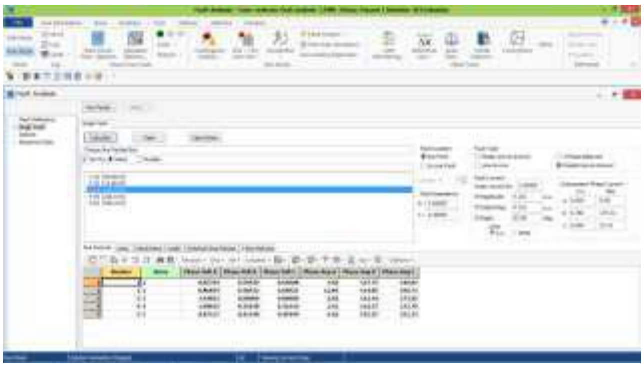

Fig. 13(a) Bus record at Bus 3 (L-L-G Fault)

Fig. 13(b) branches records at Bus 3 (L-L-G Fault)

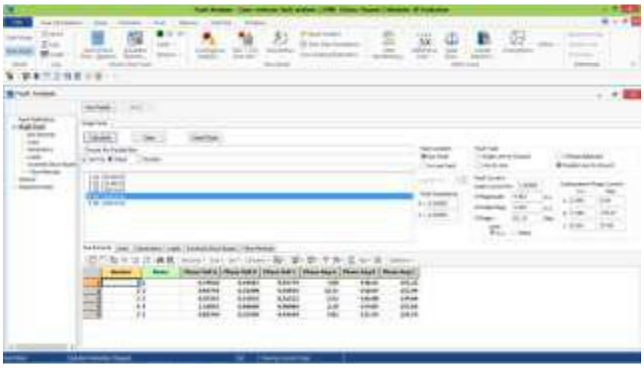

Fig. 14(a) Bus record at Bus 4 (L-L-G Fault)

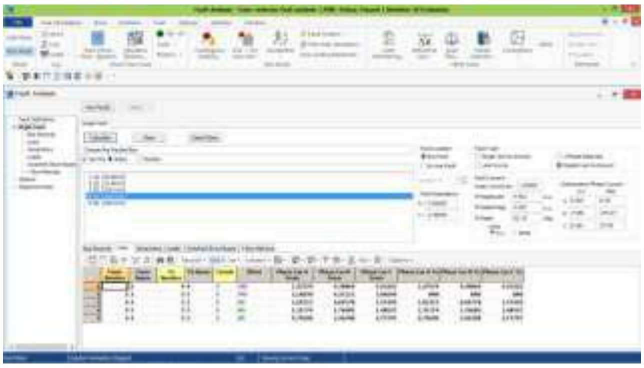

Fig. 14(b) branches records at Bus 4 (L-L-G Fault)

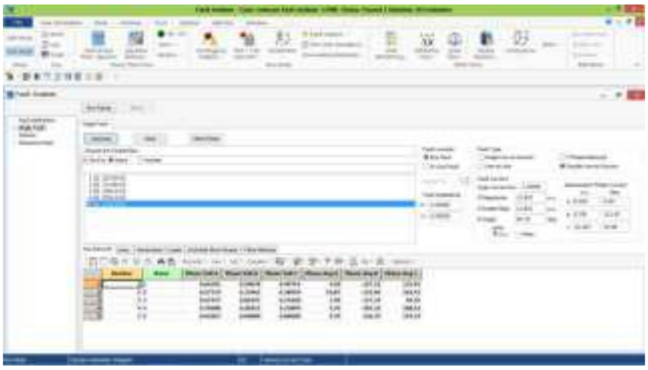

Fig. 15(a) Bus record at Bus 5 (L-L-G Fault)

Fig. 15(b) branches records at Bus 5 (L-L-G Fault)

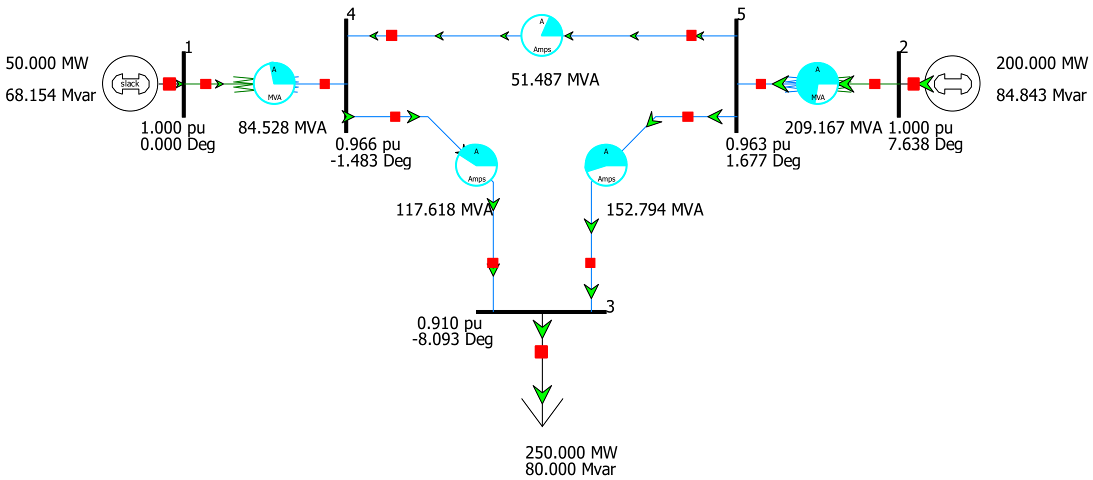

Fig. 16 Power flow analysis under steady state condition