Three Phase Balanced Fault Analysis of 6-Bus Power System using Power World Simulator

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***Abstract*— Electrical fault is the deviation of currents and voltages from nominal values or states. Under steady state operating conditions, power system lines or equipments carry normal voltages and currents which results in a safer operation of the system network. However when fault occurs, it causes excessively high currents to flow which causes the damage to equipments and devices. In this paper, Power World Simulator tool is employed to determine fault current distribution and bus voltage levels during three phase balanced fault conditions of 6-bus power system model in order to give information for the selection and coordination of suitable switchgear equipments, electromechanical relays, circuit breakers and other protection devices.**

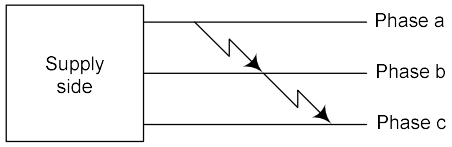
***Keywords*— fault analysis, three phase balanced fault, fault current, bus voltage, powerworld simulator**

I. INTRODUCTION

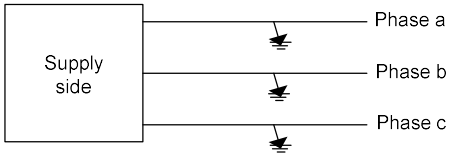
The steady state operating conditions of a power system is balanced three phase a.c . But, due to sudden internal or external changes in the system, this condition is disrupted. When the insulation the system fails at one or more points or a conducting object comes into contact with a live point, a short circuit or a fault occurs. Faults may lead to fire breakout that consequently results into loss of life, loss of property, cut of supply in areas beyond the fault point in a transmission and distribution network leading to power blackouts and destruction of a system network. All the above results into delayed development due to low gross product realised. Therefore, it is necessary to determine the values of system voltages and currents during three phase balanced fault conditions, so that protective devices may be located to detect and minimize the harmful effects. Three phase balanced faults may be analysed using an equivalent single phase circuit. Normally, fault analysis is calculated in per-unit quantities as they provide 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 three phase balanced fault of 6-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 Power World, further aiding students' learning process and utility engineers.

A. Three Phase Balanced Fault

Three phase fault is a condition where either (a) all 3- phase are short circuited to each other, or (b) all 3-phase of the system are earth. This fault is a balanced condition and needed to only know the positive-sequence network to analyse the faults. Normally, only 5% of the initial faults in a power system, are three phase balanced fault with or without earth.



(a) 3-phase to each other



(b) 3 phase to earth fault

Fig. 1 Three phase balance fault

B. Description of Per Unit Quantities

Percentage quantities or per unit quantities are actually fractional quantities of a reference quantity. These have a lot of significance as per unit quantities of parameters tend to have similar values even when the voltage and rating change drastically. Per unit system allows multiplication and division in addition to addition and subtraction without the requirement of a correction factor. Per-unit values are noted that "pu" after the value. For power, current, voltage and impedance, the p.u quantity may be calculated by dividing by the respective base of that quantity. Expressions such as Ohm's Law can be used for per unit quantities as well. Since power, voltage, current and impedance are linked; only reference quantities or two base can be independently defined. The base quantities for the other two can be calculated there from.

$$S_{pu} = \frac{S}{S_{base}}\ , V_{pu} = \frac{V}{V_{base}}\ , I_{pu} = \frac{I}{I_{base}}\ ,\ \ Z_{pu} = \frac{Z}{Z_{base}}$$

C. Description of PowerWorld Simulator to Fault Analysis

Fault analysis can be better understood by using PowerWorld simulator tool. This simulator tool allow for the easy simulation of bus systems that would take a significant amount of time if done by hand calculation. One such system is 6-bus power system model. PowerWorld's extensive range of products give the tools needed by transmission planners, system operators and trainers, educators, power marketers, and anyone else desiring access to power system information and analysis in a user friendly format. The single line diagrams are calculated for the benefit of the users. The integrated drawing tools provide an easy and fast approach to creating single line diagrams where a single line is described to represent three phases of a power system.

II. THREE PHASE BALANCED FAULT ANALYSIS RESULTS USING POWERWORLD SIMULATOR

A. Input Data of 6-Bus Power System Model

Fig. 2 shows single line diagram of 6-bus power system model under steady state condition by using powerworld simulator.Input data for the Simulator include synchronous generator, load and transmission line data as illustrated in Tables I, and II . Let's the prefault voltage $V_F = 1.0\angle 0$ **H**, fault impedance Z_F =0 and bus 1 is slack bus.

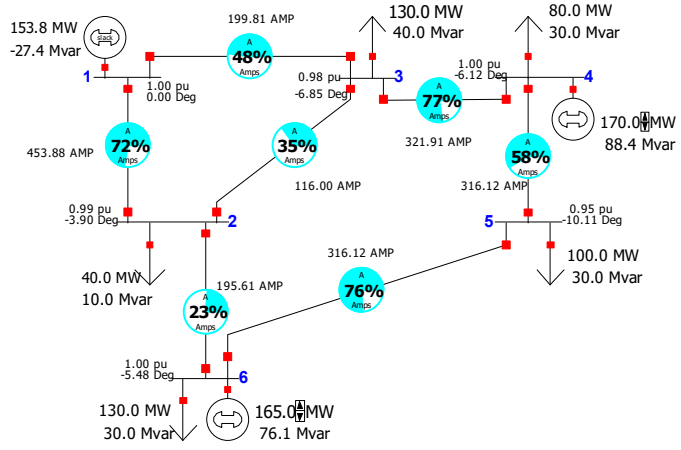


Fig. 2 Single Line Diagram of 6-bus power system under steady state condition

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

TABLE I

GENERATORS & LOADS INPUT DATA OF 6-BUS POWER SYSTEM MODEL

Bus	V p.u	δ p.u	P_G	Q_G	P_L	Q_L
1	1.0	0	-	-	0	0
2	-	-	0	0	0.4	0.1
3	-	-	0	0	1.3	0.4
4	1	-	1.7	0	0.8	0.3
5	-	-	0	0	1	0.3
6	1	-	1.65	0	1.3	0.3

TABLE II

TRANSMISSION LINES INPUT DATA OF 6- BUS POWER SYSTEM MODEL

Bus to Bus	R p.u	X p.u	B p.u	Max MVA p.u
1– 2	0.02	0.06	0.06	1
1– 3	0.08	0.24	0.05	1
2 – 3	0.06	0.18	0.04	1
2 – 6	0.02	0.06	0.05	1
3 – 4	0.01	0.03	0.02	1
4– 5	0.08	0.24	0.05	1
5 – 6	0.04	0.12	0.03	1

B. Three Phase Balanced Fault Analysis Results of 6-Bus Power System Model (Case Study I – Bus fault)

After three phase balanced fault type is selected in fault analysis dialog at run mode condition, three phase balanced 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, bus 5 and bus 6. Three phase balanced fault analysis results are shown in Table III and IV.

TABLE III

BRANCHES RESULT DATA OF 6- BUS POWER SYSTEM MODEL

Fault Bus	Subtransient Current (Phase A,B and C)			Fault Current			
				Bus To Bus	Phase A	Phase B	Phase C
	p.u	Amp	Deg		p.u	p.u	p.u
1	4.950	2071	-52.15	1– 2	2.46847	2.46847	2.46847
	4.950	2071	-172.15	1– 3	1.05069	1.05069	1.05069
	4.950	2071	67.85	2 – 3	0.58151	0.58151	0.58151
				2 – 6	1.9203	1.9203	1.9203
				3 – 4	1.86002	1.86002	1.86002
				4– 5	0.19663	0.19663	0.19663
				5 – 6	0.17662	0.17662	0.17662
2	5.346	2236	-50.63	1– 2	1.88535	1.88535	1.88535
	5.346	2236	-170.6	1– 3	0.47586	0.47586	0.47586
	5.346	2236	69.37	2 – 3	1.15685	1.15685	1.15685
				2 – 6	2.39686	2.39686	2.39686
				3 – 4	1.76407	1.76407	1.76407
				4– 5	0.36582	0.36582	0.36582
				5 – 6	0.26406	0.26406	0.26406
3	5.339	2233	-50.90	1– 2	0.62149	0.62149	0.62149
	5.339	2233	-170.9	1– 3	1.06686	1.06686	1.06686

	5.339	2233	69.10	2 – 3	1.33071	1.33071	1.33071
				2 – 6	1.22883	1.22883	1.22883
				3 – 4	2.95954	2.95954	2.95954
				4– 5	0.56275	0.56275	0.56275
				5 – 6	0.74258	0.74258	0.74258
4	5.407	2262	-51.58	1– 2	0.66239	0.66239	0.66239
	5.407	2262	-171.6	1– 3	0.94804	0.94804	0.94804
	5.407	2262	68.42	2 – 3	1.14077	1.14077	1.14077
				2 – 6	0.97551	0.97551	0.97551
				3 – 4	2.0436	2.0436	2.0436
				4– 5	0.84035	0.84035	0.84035
				5 – 6	0.999	0.999	0.999
5	4.428	1852	-54.89	1– 2	1.06254	1.06254	1.06254
	4.428	1852	-174.9	1– 3	0.34616	0.34616	0.34616
	4.428	1852	65.11	2 – 3	0.21816	0.21816	0.21816
				2 – 6	0.91927	0.91927	0.91927
				3 – 4	0.2431	0.2431	0.2431
				4– 5	1.66913	1.66913	1.66913
				5 – 6	2.75103	2.75103	2.75103
6	5.435	2273	-50.51	1– 2	1.56815	1.56815	1.56815
	5.435	2273	-170.5	1– 3	0.33736	0.33736	0.33736
	5.435	2273	69.49	2 – 3	0.77988	0.77988	0.77988
				2 – 6	2.23882	2.23882	2.23882
				3 – 4	1.19928	1.19928	1.19928
				4– 5	0.86584	0.86584	0.86584
				5 – 6	0.8021	0.8021	0.8021

TABLE IV

BUS RESULTS DATA OF 6- BUS POWER SYSTEM MODEL

$V_{prefault}$ =1.0 ∠0		Bus Voltages during Fault		
Fault Bus	Bus	Phase A	Phase B	Phase C
1	1	0.00000	0.00000	0.00000
	2	0.15612	0.15612	0.15612
	3	0.26581	0.26581	0.26581
	4	0.32394	0.32394	0.32394
	5	0.27716	0.27716	0.27716
	6	0.27727	0.27727	0.27727
2	1	0.11945	0.11945	0.11945
	2	0.00000	0.00000	0.00000
	3	0.2195	0.2195	0.2195
	4	0.27518	0.27518	0.27518
	5	0.18248	0.18248	0.18248
	6	0.15159	0.15159	0.15159
3	1	0.27153	0.27153	0.27153
	2	0.2534	0.2534	0.2534
	3	0.00000	0.00000	0.00000
	4	0.09359	0.09359	0.09359
	5	0.23523	0.23523	0.23523
	6	0.32601	0.32601	0.32601
4	1	0.30594	0.30594	0.30594
	2	0.28208	0.28208	0.28208
	3	0.06464	0.06464	0.06464
	4	0.00000	0.00000	0.00000
	5	0.21259	0.21259	0.21259
	6	0.33691	0.33691	0.33691
5	1	0.46409	0.46409	0.46409
	2	0.405	0.405	0.405
	3	0.41728	0.41728	0.41728
	4	0.42481	0.42481	0.42481
	5	0.00000	0.00000	0.00000
	6	0.34798	0.34798	0.34798
6	1	0.24007	0.24007	0.24007
	2	0.14181	0.14181	0.14181
	3	0.28436	0.28436	0.28436
	4	0.32215	0.32215	0.32215
	5	0.10164	0.10164	0.10164
	6	0.00000	0.00000	0.00000

B. Three Phase Balanced Fault Analysis Results of 6-Bus Power System Model (Case Study II- In line fault)

After three phase balanced fault type is selected in fault analysis dialog at run mode condition, three phase balanced fault is calculated consist of the fault current in each phase, contributions to the fault current from each branch connected to the bus for each phase and the voltages for a fault in transmission lines. Three phase balanced fault analysis results are shown in Table III and IV.

TABLE V

BRANCHES RESULT DATA OF 6- BUS POWER SYSTEM MODEL

Line Fault (50 % location between lines)	Subtransient Current (Phase A, B and C)			Fault current			
				Bus to Bus	Phase A	Phase B	Phase C
	p.u	Amp	Deg		p.u	p.u	p.u
1– 2	5.075	2123	-51.77	1– 2	0.0000	0.0000	0.0000
	5.075	2123	-171.78	1– 3	0.7585	0.7585	0.7585
	5.075	2123	68.23	1 – Fault	2.2273	2.2273	2.2273
				2 – 3	0.8465	0.8465	0.8465
				2 – 6	2.1259	2.1259	2.1259
				Fault– 2	2.9520	2.9520	2.9520
				3 – 4	1.7998	1.7998	1.7998
				4– 5	0.2762	0.2762	0.2762

				5 – 6	0.1817	0.1817	0.1817
1– 3	4.344	1817	-55.5	1– 2	1.1615	1.1615	1.1615
	4.344	1817	-175.5	1– 2	0.0000	0.0000	0.0000
	4.344	1817	64.50	1– Fault	2.1777	2.1777	2.1777
				2 – 3	0.3324	0.3324	0.3324
				2 – 6	1.3832	1.3832	1.3832
				3 – 4	2.1301	2.1301	2.1301
				Fault– 3	2.1949	2.1949	2.1949
				4– 5	0.1460	0.1460	0.1460
				5 – 6	0.4538	0.4538	0.4538
2 – 3	4.752	1987	-54.10	1– 2	1.0914	1.0914	1.0914
	4.752	1987	-174.1	1– 3	0.3864	0.3864	0.3864
	4.752	1987	65.90	2 – 3	0.0000	0.0000	0.0000
				2 – 6	1.6376	1.6376	1.6376
				2– Fault	2.4691	2.4691	2.4691
				3 – 4	2.1782	2.1782	2.1782
				Fault-3	2.2882	2.2882	2.2882
				4 – 5	0.0967	0.0967	0.0967
				5 – 6	0.3421	0.3421	0.3421
2 – 6	5.332	2230	-50.95	1– 2	1.7123	1.7123	1.7123
	5.332	2230	-170.9	1– 3	0.3989	0.3989	0.3989
	5.332	2230	69.05	2 – 3	0.9587	0.9587	0.9587
				2 – 6	0.0000	0.0000	0.0000
				2– Fault	2.5862	2.5862	2.5862
				3 – 4	1.4753	1.4753	1.4753
				4 – 5	0.6090	0.6090	0.6090
				5 – 6	0.5145	0.5145	0.5145
				Fault – 6	2.7718	2.7718	2.7718
3 – 4	5.359	2242	-51.3	1– 2	0.6421	0.6421	0.6421
	5.359	2242	-171	1– 3	1.0053	1.0053	1.0053
	5.359	2242	68.6	2 – 3	1.2333	1.2333	1.2333
				2 – 6	1.1004	1.1004	1.1004
				3 – 4	0.0000	0.0000	0.0000
				3– Fault	2.2172	2.2172	2.2172
				4 – 5	0.6983	0.6983	0.6983
				Fault – 4	3.1603	3.1603	3.1603
				5 – 6	0.8689	0.8689	0.8689
4 – 5	4.301		-57.10	1– 2	0.8594	0.8594	0.8594
	4.301		-177.1	1– 3	0.5320	0.5320	0.5320
	4.301		62.90	2 – 3	0.4501	0.4501	0.4501
				2 – 6	0.3495	0.3495	0.3495
				3 – 4	0.6130	0.6130	0.6130
				4 – 5	0.0000	0.0000	0.0000
				4 – Fault	2.6544	2.6544	2.6544
				5 – 6	1.7916	1.7916	1.7916
				Fault – 5	1.6433	1.6433	1.6433
5 – 6				1– 2	1.2506	1.2506	1.2506
				1– 3	0.3023	0.3023	0.3023
				2 – 3	0.4223	0.4223	0.4223
				2 – 6	1.4547	1.4547	1.4547
				3 – 4	0.6720	0.6720	0.6720
				4 – 5	1.2740	1.2740	1.2740
				5.6	0.0000	0.0000	0.0000
				5 – Fault	1.2309	1.2309	1.2309
				Fault – 6	3.5040	3.5040	3.5040

TABLE VI
BUS RESULTS DATA OF 6- BUS POWER SYSTEM MODEL

Line Fault		Bus Voltages during Fault		
(50 % location between lines)	Bus	Phase A	Phase B	Phase C
1– 2	1	0.0705	0.0705	0.0705
	2	0.09339	0.09339	0.09339
	3	0.25367	0.25367	0.25367
	4	0.31028	0.31028	0.31028
	5	0.24158	0.24158	0.24158
	6	0.22385	0.22385	0.22385
	Fault Pt	0.00000	0.00000	0.00000
1– 3	1	0.27629	0.27629	0.27629
	2	0.33482	0.33482	0.33482
	3	0.27805	0.27805	0.27805
	4	0.34519	0.34519	0.34519
	5	0.37353	0.37353	0.37353
	6	0.41077	0.41077	0.41077
	Fault Pt	0.00000	0.00000	0.00000
2 – 3	1	0.29662	0.29662	0.29662
	2	0.23466	0.23466	0.23466
	3	0.21727	0.21727	0.21727
	4	0.28608	0.28608	0.28608
	5	0.30153	0.30153	0.30153
	6	0.32261	0.32261	0.32261
	Fault Pt	0.00000	0.00000	0.00000
2 – 6	1	0.18966	0.18966	0.18966
	2	0.08184	0.08184	0.08184
	3	0.26081	0.26081	0.26081
	4	0.30738	0.30738	0.30738
	5	0.15231	0.15231	0.15231
	6	0.08467	0.08467	0.08467
	Fault Pt	0.00000	0.00000	0.00000
3 – 4	1	0.29099	0.29099	0.29099
	2	0.27000	0.27000	0.27000
	3	0.03506	0.03506	0.03506
	4	0.04997	0.04997	0.04997

	5	0.22626	0.22626	0.22626
	6	0.31652	0.31652	0.31652
	Fault Pt	0.00000	0.00000	0.00000
4– 5	1	0.47822	0.47822	0.47822
	2	0.43886	0.43886	0.43886
	3	0.35625	0.35625	0.35625
	4	0.33677	0.33677	0.33677
	5	0.20817	0.20817	0.20817
	6	0.41604	0.41604	0.41604
	Fault Pt	0.00000	0.00000	0.00000
	1	0.38815	0.38815	0.38815
	2	0.31356	0.31356	0.31356
	3	0.38143	0.38143	0.38143
	4	0.40252	0.40252	0.40252
	5	0.07792	0.07792	0.07792
	6	0.20895	0.20895	0.20895
	Fault Pt	0.00000	0.00000	0.00000

III. CONCLUSION

This paper described symmetrical fault or three phase balanced fault analysis of 6-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 give information for the selection and coordination of protective equipment to ensure the safe and reliable operation of the system. This fault analysis was created using the student version of PowerWorld simulator that is limited to 13 buses. The full version is relatively inexpensive and provides the user capability to model much larger and complex power system networks.

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APPENDIX

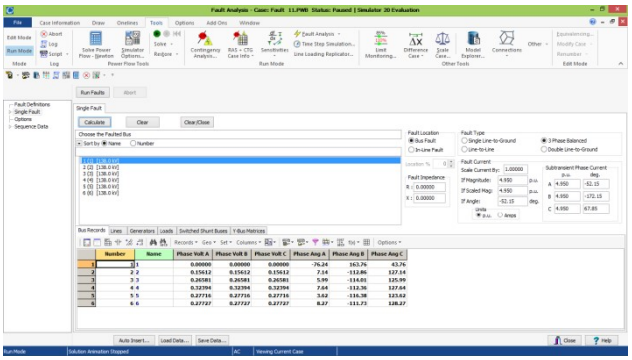

Fig. 1(a) Bus voltage records at bus 1

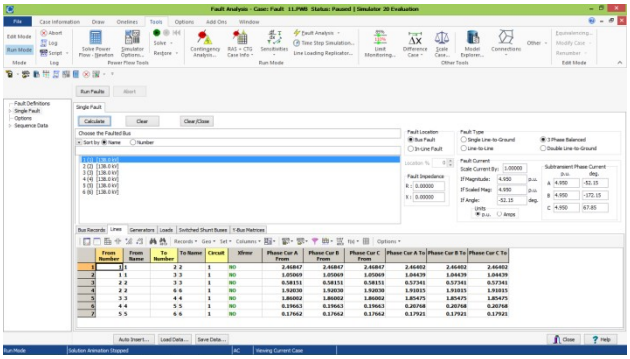

Fig. 1(b) Branch current records at bus 1

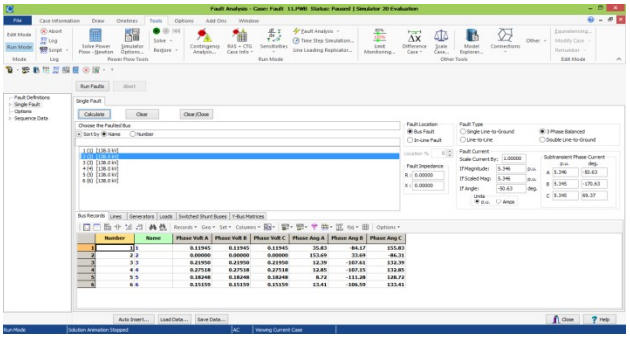

Fig. 2(a) Bus voltage records at bus 2

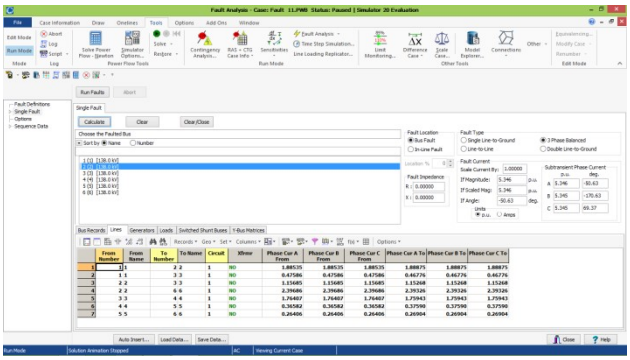

Fig. 2(b) Branch current records at bus 2

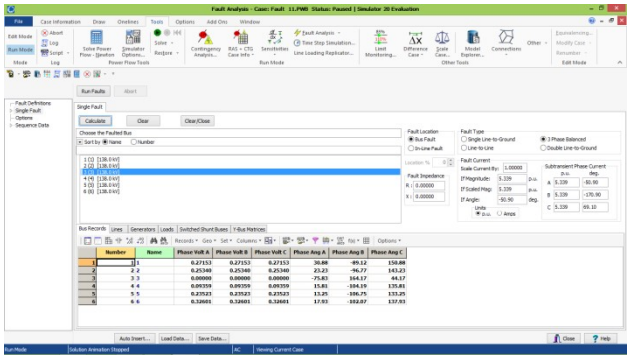

Fig. 3(a) Bus voltage records at bus 3

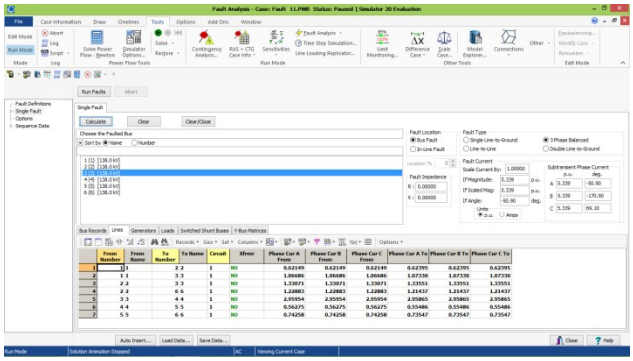

Fig. 3(b) Branch current records at bus 3

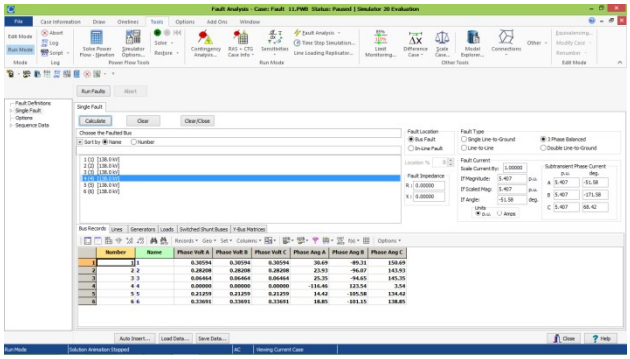

Fig. 4(a) Bus voltage records at bus 4

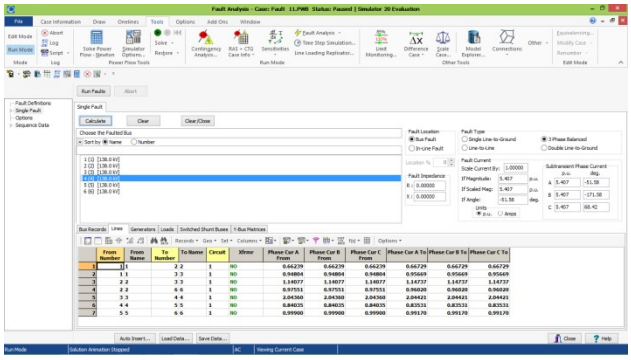

Fig. 4(b) Branch current records at bus 4

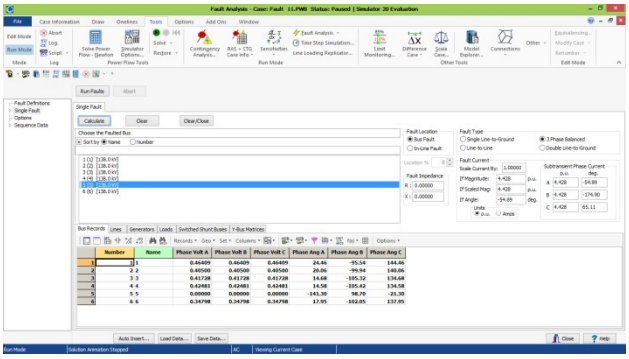

Fig. 5(a) Bus voltage records at bus 5

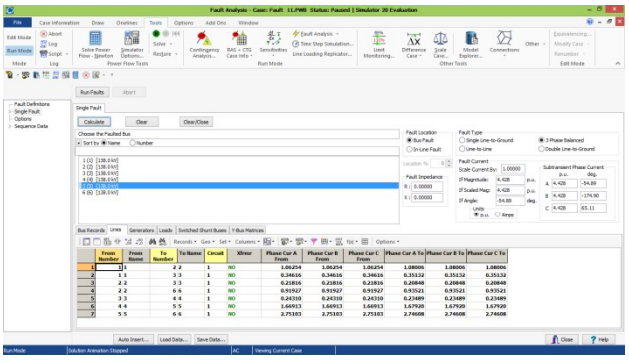

Fig. 5(b) Branch current records at bus 5

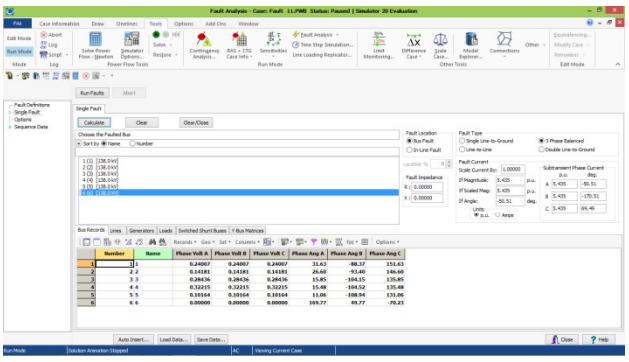

Fig. 6(a) Bus voltage records at bus 6

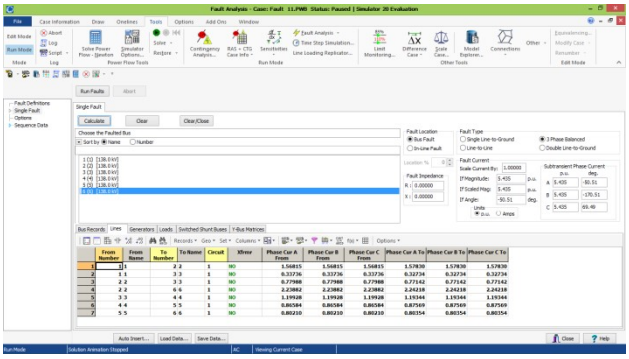

Fig. 6(b) Branch current records at bus 6

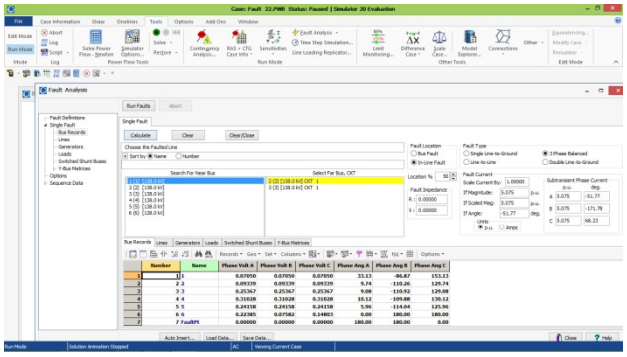

Fig. 7(a) Bus voltage records at line1-2

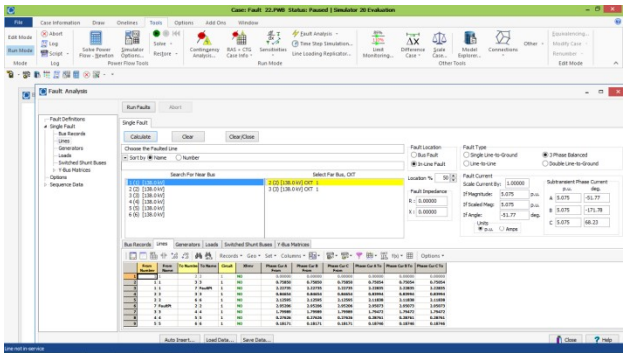

Fig. 7(b) Branch current records at line 1-2

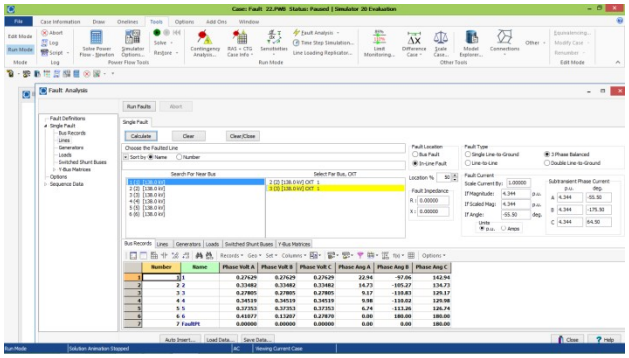

Fig. 8(a) Bus voltage records at line1-3

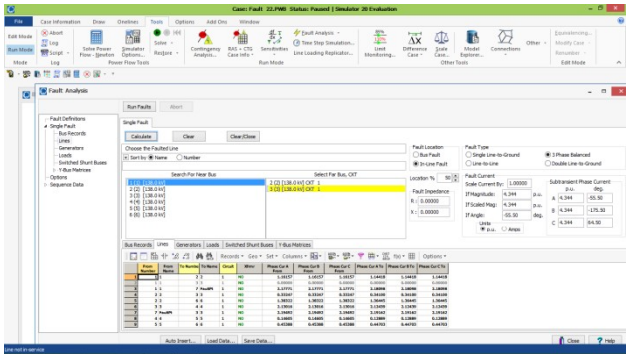

Fig. 8(b) Branch current records at line 1-3

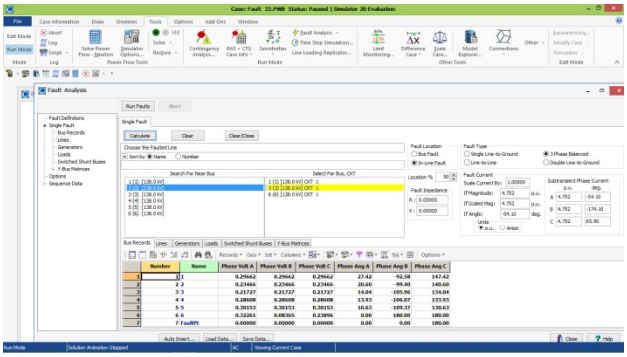

Fig. 9(a) Bus voltage records at line 2-3

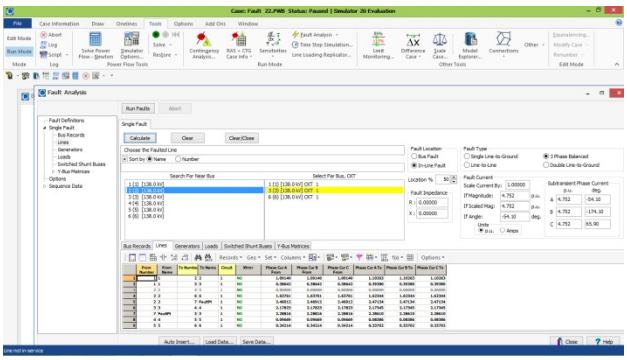

Fig. 9(b) Branch current records at line 2-3

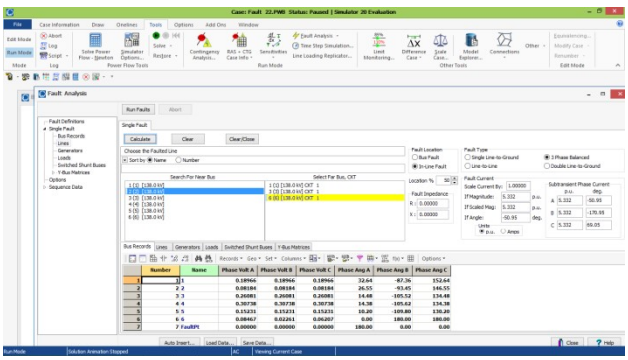

Fig. 10(a) Bus voltage records at line 2-6

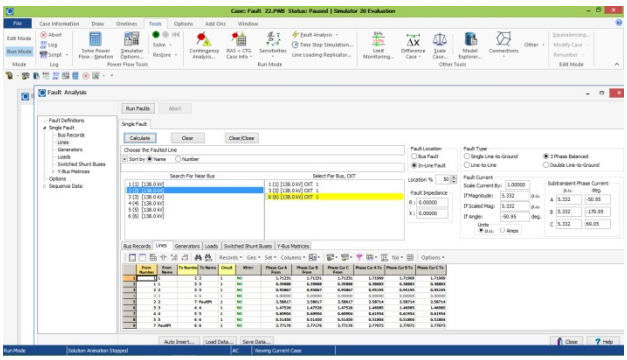

Fig. 10(b) Branch current records at line 2-6

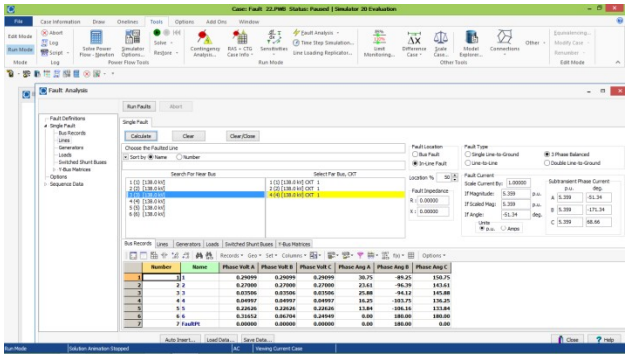

Fig. 11(a) Bus voltage records at line 3-4

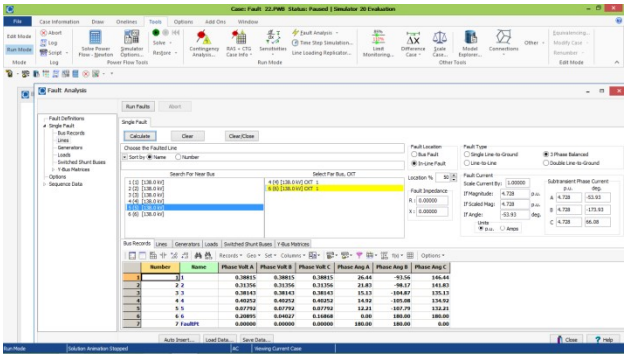

Fig. 13(a) Bus voltage records at line 5-6

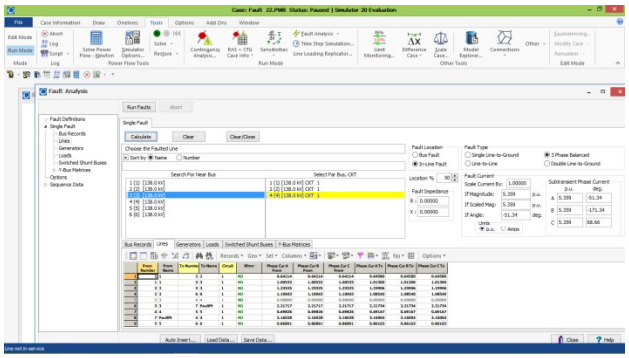

Fig. 11(b) Branch current records at line 3-4

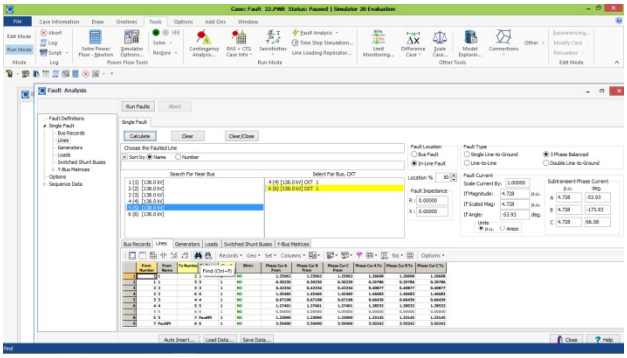

Fig. 13(b) Branch current records at line 5-6

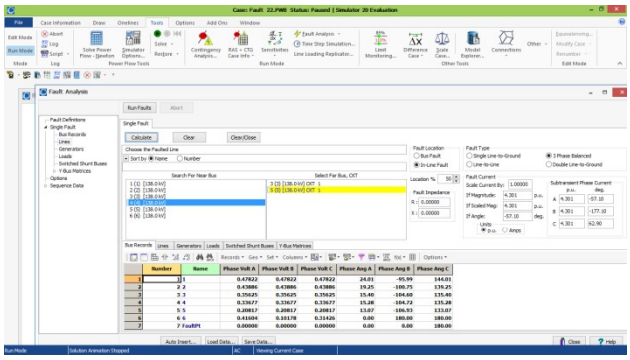

Fig. 12(a) Bus voltage records at line 4-5

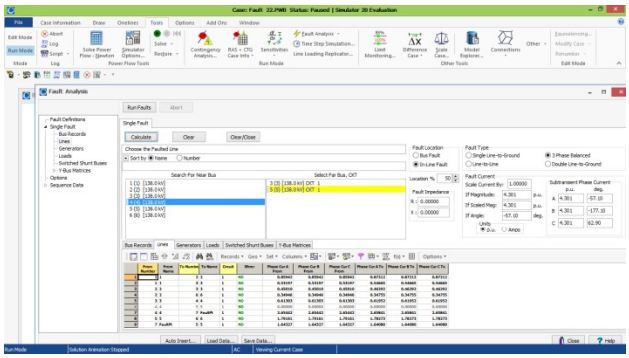

Fig. 12(b) Branch current records at line 4-5

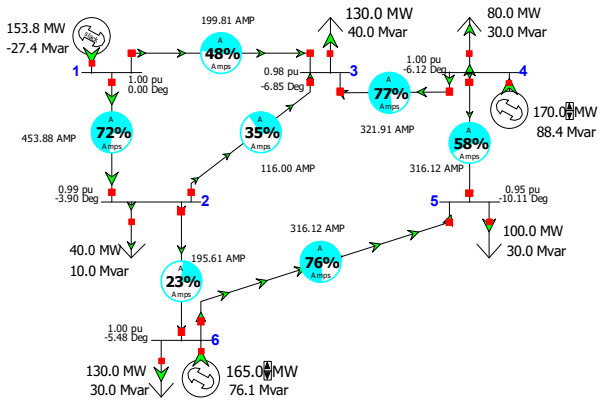

Fig. 14 Load flow analysis under steady state condition