Fault Analysis of 9-Bus Test System

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Abstract - *Fault analysis is an important consideration in power system planning, protection equipment selection, and overall system reliability assessment. At the heart of today's power generation and distribution are high-voltage transmission and distribution networks. When a fault (e.g., a short circuit) occurs at some point in the network, the normal operating conditions of the system are upset; if the fault is persistent severe loss of load, property damage due to fire or explosion, and steep economic losses can arise as undesirable consequences. Therefore, the correct modelling of components and the correct fault analysis in power systems are critical to ensuring safety and reliability.*

The aim of the project is to conduct fault analysis both symmetrical and unsymmetrical Faults are studied. Fault analysis enables to determine the change in system parameter due to A fault and the variation is supply by various sources to loads. the analysis enables us to determine the critical and noncritical elements of a power system.

Key Words: *Optimal power flow, power world simulator, voltage security, SVC*

I INTRODUCTION

The fault analysis of a power system is required in order to provide information for the Selection of switchgear, setting of relays and stability of system operation. 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. Faults usually occur in a power system due to insulation failure, flashover, and physical damage or human error. These faults, may either be three phase in nature involving all three phases in a symmetrical manner, or may be asymmetrical where usually only one or two phases may be involved.

Faults may also be caused by either short-circuits to earth or between live conductors, or may be caused by broken conductors in one or more phases. Sometimes simultaneous faults may occur involving both short-circuit and broken conductor faults (also known as open-circuit faults).Balanced three phase faults may be analyzed using an equivalent single phase circuit. With asymmetrical three phase faults, the use of symmetrical components help to reduce the complexity of the calculations as transmission lines and components are by and large symmetrical, although the fault may be asymmetrical. Fault analysis is usually carried out in per-unit quantities (similar to percentage quantities)as they give solutions which are somewhat consistent over different voltage and power ratings, and operate on values of the order of unity.

II LITERATURE SURVEY

Simulator can model generators as not having a cost model, or having either a cubic cost model or a piecewise linear model. The cost model type you choose determines the content of the remainder of this dialog

2.1 Fault in Power System

In an electric power system, a fault is any abnormal operation. For example, a short circuit is a fault in which current by passes the normal load. An open-circuit fault occurs if a circuit is interrupted by some failure. In three-phase systems, a fault may involve one or more phases and ground, or may occur only between phases.

2.2 Causes of Fault in Power System

- Lighting strokes cause most faults on high-voltage transmission lines producing a very high transient that greatly exceeds the rated voltage of the line.
- This voltage usually causes flashover between the phases and/or the ground creating an arc.
- Since the impedance of this new path is usually low, an excessive current may flow.
- Faults involving ionized current paths are also called transient faults. They usually clear if power is removed from the line for a short time and then restored.

2.3 Need of Fault Analysis in Power System

- Electric systems occasionally experience short circuits.
- This results in abnormally high currents.
- Over current protective devices should isolate faults at a given location safely, with minimal damage.

- The parts of system shall be able to withstand the resulting mechanical and thermal stresses.
- The magnitudes of fault currents are usually estimated by calculations.
- The equipment is selected using the calculation results

2,4 Fault limiting devices

It is possible to minimize causes like human errors, but not environmental changes. Fault clearing is a crucial task in power system network. If we manage to disrupt or break the circuit when fault arises, it reduces the considerable damage to the equipments and also property.
Some of these fault limiting devices include fuses, circuit breakers, relays, etc. and are discussed below.

- Fuse
- Circuit Breaker
- Relay
- Lighting power protection devices

III POWER SYSTEM UNDER STUDY

This paper studies the optimal power flow (OPF) problem in distribution networks, which includes cost economics of 9-bus system following we present a model of this scenario that serves as the basis for our analysis. The model incorporates power flow in 9 bus system which, considers a variety of devices including distributed generators, transformers, controllable loads and allows for a wide range of control objectives such as minimizing the power loss or generation cost, which are described in turn.

3.1 TEST DATA FOR ANALYSIS OF SYSTEM

3.1.a.Bus Data

Bus										
Number	Name	Area Name	Nom Kv	PU Volt	Volt (kV)	Angle (Deg)	Load MW	Load Mvar	Gen MW	Gen Mvar
1	1	1	138	1	138	0			72.07	9.53
2	2	1	138	1	138	-17.42			85	-36.59
3	3	1	138	1	138	-11.21			163	-36.33
4	4	1	138	1.03226	142.452	-23.71				
5	5	1	138	1.03086	142.259	-24.32	90	0		
6	6	1	138	1.02575	141.553	-16.55				
7	7	1	138	1.02634	141.635	-21.13	100	0		
8	8	1	138	1	141.62	-21.13				
9	9	1	138	1	142.5	-15.12	150	0		

3.1.b.Branch Data

Bus From Number	To Number	R	X	B
1	4	0	0.576	0
2	2	0	0.0625	0
3	6	0	0.0586	0
4	5	0.017	0.092	0.158
5	9	0.01	0.085	0.176
6	6	0.039	0.17	0.358
7	7	0.0119	0.1008	0.209
8	8	0.0085	0.072	0.149
9	2	0	0.0625	0
10	9	0.032	0.161	0.306
11	4	0.01	0.085	0.176

3.1.c. Generator Data

Generator					
Number of Bus	Name of Bus	ID	Status	Gen MW	Gen Mvar
1	1	1	Closed	72.07	9.53
2	2	1	Closed	85	-36.59
3	3	1	Closed	163	-36.33

3.2 ELECTRIC MODEL

3.2.1 SINGLE LINE DIAGRAM

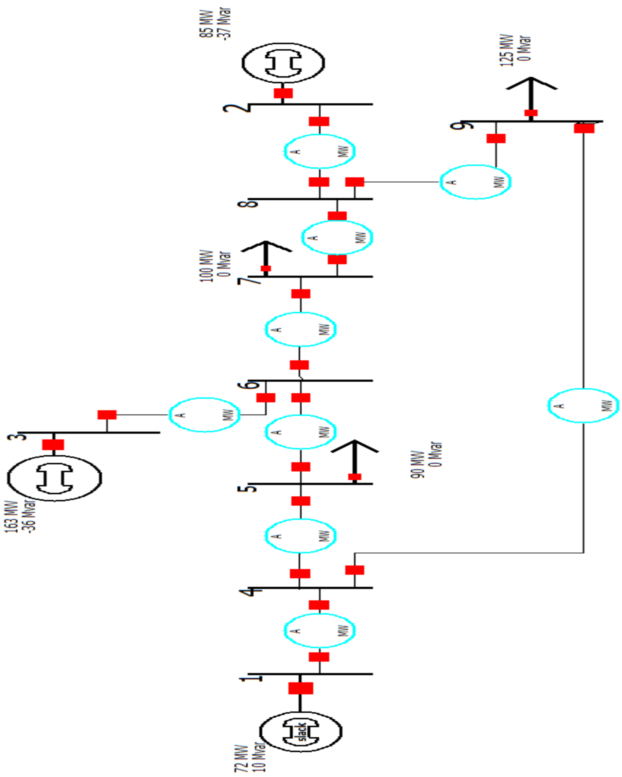


Fig.1 single line diagram for test data

3.3 System study and analysis

3.3.1 System with no fault

Bus data

	Number	Name	Area Name	Nom kV	PU Volt	Volt (kV)	Angle (Deg)	Load MW	Load Mvar	Gen MW	Gen Mvar	Switched Shunts Mvar	Act G Shunt MW	Act B Shunt Mvar	Area Num
1	1	1	1	138.00	1.00000	138.000	0.00			68.81	11.87		0.00	0.00	1
2	2	2	1	138.00	1.00000	138.000	-8.81			165.00	-21.97		0.00	0.00	1
3	3	3	1	138.00	1.00000	138.000	-9.82			150.00	-27.11		0.00	0.00	1
4	4	4	1	138.00	1.01243	139.715	-23.05						0.00	0.00	1
5	5	5	1	138.00	1.00452	138.624	-25.38	150.00	0.00				0.00	0.00	1
6	6	6	1	138.00	1.01968	140.716	-14.77						0.00	0.00	1
7	7	7	1	138.00	1.02122	140.928	-17.04	100.00	0.00				0.00	0.00	1
8	8	8	1	138.00	1.01896	140.617	-14.62						0.00	0.00	1
9	9	9	1	138.00	1.01060	139.462	-24.17	125.00	0.00				0.00	0.00	1

Fig: Bus Data

Branch Data

	From Number	From Name	To Number	To Name	Circuit	Status	Branch Device Type	Xfrmr	MW From	Mvar From	MVA From	Lim MVA	% of MVA Limit (Max)	MW Loss	Mvar Loss
1	1	1	4	4	1	Closed	Line	NO	68.8	11.9	69.8	0.0	0.0	0.00	28.08
2	8	8	2	2	1	Closed	Line	NO	-165.0	39.3	169.6	0.0	0.0	0.00	17.32
3	3	3	6	6	1	Closed	Line	NO	150.0	-27.1	152.4	0.0	0.0	0.00	13.62
4	4	4	5	5	1	Closed	Line	NO	45.2	-6.8	45.7	0.0	0.0	0.34	-14.23
5	4	4	9	9	1	Closed	Line	NO	23.6	-9.4	25.4	0.0	0.0	0.05	-17.55
6	5	5	6	6	1	Closed	Line	NO	-105.1	7.4	105.4	0.0	0.0	4.52	-16.96
7	6	6	7	7	1	Closed	Line	NO	40.4	-16.4	43.6	0.0	0.0	0.19	-20.16
8	7	7	8	8	1	Closed	Line	NO	-59.8	3.8	60.0	0.0	0.0	0.30	-12.94
9	8	8	9	9	1	Closed	Line	NO	104.9	-22.6	107.3	0.0	0.0	3.40	-14.39

Fig: Branch Data

Generator data

	Number of Bus	Name of Bus	ID	Status	Gen MW	Gen Mvar	Set Volt	AGC	AVR	Min MW	Max MW	Min Mvar	Max Mvar	Cost Model	Part. Factor
1	1	1	1	Closed	68.81	11.87	1.00000	YES	YES	0.00	1000.00	-9900.00	9900.00	Cubic	10.00
2	2	2	1	Closed	165.00	-21.97	1.00000	YES	YES	0.00	1000.00	-9900.00	9900.00	Cubic	10.00
3	3	3	1	Closed	150.00	-27.11	1.00000	YES	YES	0.00	1000.00	-9900.00	9900.00	Cubic	10.00

Fig: Generator Data

3.3.2 System With Single Line(R) to Ground Fault

Bus data

	Number	Name	Phase Volt A	Phase Volt B	Phase Volt C	Phase Ang A	Phase Ang B	Phase Ang C
1	1	1	0.00000	1.11954	1.05991	0.40	-126.19	128.59
2	2	2	0.82348	1.05288	0.98220	-6.07	-129.27	114.11
3	3	3	0.92574	1.01634	0.98464	-8.73	-129.35	110.76
4	4	4	0.67953	1.10755	0.98806	-25.74	-144.16	102.35
5	5	5	0.73712	1.09102	0.97447	-27.04	-145.98	99.36
6	6	6	0.87794	1.06163	0.99907	-14.09	-134.75	107.31
7	7	7	0.84529	1.07843	0.99693	-16.19	-137.23	105.91
8	8	8	0.81993	1.08136	0.99703	-13.20	-135.08	108.74
9	9	9	0.72017	1.10322	0.98096	-25.58	-144.93	100.94

Fig: Bus Data

Branch data

	From Number	From Name	To Number	To Name	Circuit	Xfrmr	Phase Cur A From	Phase Cur B From	Phase Cur C From	Phase Cur A To	Phase Cur B To	Phase Cur C To
1	1	1	4	4	1	NO	0.94900	0.80883	0.53458	0.94900	0.80883	0.53458
2	8	8	2	2	1	NO	1.61128	1.68074	1.61251	1.61128	1.68074	1.61251
3	3	3	6	6	1	NO	1.40500	1.48125	1.40560	1.40500	1.48125	1.40560
4	4	4	5	5	1	NO	0.55180	0.51120	0.37149	0.44608	0.48811	0.38354
5	4	4	9	9	1	NO	0.41122	0.30842	0.16615	0.28814	0.24935	0.19496
6	5	5	6	6	1	NO	1.16885	0.98038	1.04185	1.08634	1.06626	1.04304
7	6	6	7	7	1	NO	0.31866	0.42612	0.36423	0.40270	0.35234	0.37656
8	7	7	8	8	1	NO	0.63752	0.62185	0.58191	0.69791	0.64654	0.60766
9	8	8	9	9	1	NO	1.03282	1.03428	1.01010	1.08163	0.96616	1.00335

Fig: Branch Data

Generator data

	Number of Bus	Name of Bus	Phase Cur A	Phase Cur B	Phase Cur C	Phase Ang A	Phase Ang B	Phase Ang C
1	1	1	1.31339	0.80883	0.53458	-58.40	-120.40	112.40
2	2	2	1.61128	1.68074	1.61251	-7.30	-119.47	118.34
3	3	3	1.40500	1.48125	1.40560	-29.50	-112.78	114.96

Fig: Generator Data

3.3.3 System with line(R) to line(Y) fault

Bus data

	From Number	From Name	To Number	To Name	Circuit	Xfrmr	Phase Cur A From	Phase Cur B From	Phase Cur C From	Phase Cur A To	Phase Cur B To	Phase Cur C To
1	1	1	4	4	1	NO	0.94900	0.80883	0.53458	0.94900	0.80883	0.53458
2	8	8	2	2	1	NO	1.61128	1.68074	1.61251	1.61128	1.68074	1.61251
3	3	3	6	6	1	NO	1.40500	1.48125	1.40560	1.40500	1.48125	1.40560
4	4	4	5	5	1	NO	0.55180	0.51120	0.37149	0.44608	0.48811	0.38354
5	4	4	9	9	1	NO	0.41122	0.30842	0.16615	0.28814	0.24935	0.19496
6	5	5	6	6	1	NO	1.16885	0.98038	1.04185	1.08634	1.06626	1.04304
7	6	6	7	7	1	NO	0.31866	0.42612	0.36423	0.40270	0.35234	0.37656
8	7	7	8	8	1	NO	0.63752	0.62185	0.58191	0.69791	0.64654	0.60766
9	8	8	9	9	1	NO	1.03282	1.03428	1.01010	1.08163	0.96616	1.00335

Fig: Bus Data

Branch data

	Number	Name	Phase Volt A	Phase Volt B	Phase Volt C	Phase Ang A	Phase Ang B	Phase Ang C
1	1	1	0.00000	1.11954	1.05991	0.40	-126.19	128.59
2	2	2	0.82348	1.05288	0.98220	-6.07	-129.27	114.11
3	3	3	0.92574	1.01634	0.98464	-8.73	-129.35	110.76
4	4	4	0.67953	1.10755	0.98806	-25.74	-144.16	102.35
5	5	5	0.73712	1.09102	0.97447	-27.04	-145.98	99.36
6	6	6	0.87794	1.06163	0.99907	-14.09	-134.75	107.31
7	7	7	0.84529	1.07843	0.99693	-16.19	-137.23	105.91
8	8	8	0.81993	1.08136	0.99703	-13.20	-135.08	108.74
9	9	9	0.72017	1.10322	0.98096	-25.58	-144.93	100.94

Fig: Branch Data

Generator data

	Number of Bus	Name of Bus	Phase Cur A	Phase Cur B	Phase Cur C	Phase Ang A	Phase Ang B	Phase Ang C
1	1	1	1.31339	0.80883	0.53458	-58.40	-120.40	112.40
2	2	2	1.61128	1.68074	1.61251	-7.30	-119.47	118.34
3	3	3	1.40500	1.48125	1.40560	-29.50	-112.78	114.96

Fig: Generator Data

3.3.4 System with double line(Y & B) to ground fault

Bus data

	Number	Name	Phase Volt A	Phase Volt B	Phase Volt C	Phase Ang A	Phase Ang B	Phase Ang C
1	1	1	1.13994	0.00000	0.00000	1.40	8.87	-7.45
2	2	2	1.03081	0.78966	0.86216	-6.87	-123.71	115.48
3	3	3	1.00140	0.90077	0.93379	-8.92	-128.62	112.65
4	4	4	1.07298	0.63785	0.73335	-19.86	-141.56	96.45
5	5	5	1.05370	0.69240	0.79108	-22.22	-143.25	95.19
6	6	6	1.03895	0.84602	0.90443	-13.07	-132.74	107.46
7	7	7	1.05051	0.80784	0.88438	-14.85	-133.92	105.55
8	8	8	1.05448	0.78312	0.86320	-12.35	-130.51	108.48
9	9	9	1.06511	0.67417	0.77853	-20.89	-141.31	96.73

Fig: Bus Data

Branch data

	From Number	From Name	To Number	To Name	Circuit	Xfrmr	Phase Cur A From	Phase Cur B From	Phase Cur C From	Phase Cur A To	Phase Cur B To	Phase Cur C To
1	1	1	4	4	1	NO	0.66063	0.91105	1.29025	0.66063	0.91105	1.29025
2	8	8	2	2	1	NO	1.63443	1.57982	1.58751	1.63443	1.57982	1.58751
3	3	3	6	6	1	NO	1.37241	1.49674	1.16817	1.37241	1.49674	1.16817
4	4	4	5	5	1	NO	0.43796	0.52035	0.73197	0.42487	0.41529	0.61881
5	4	4	9	9	1	NO	0.23288	0.41035	0.57402	0.19542	0.30621	0.44101
6	5	5	6	6	1	NO	0.97880	1.27307	1.06068	1.01507	1.15908	0.95154
7	6	6	7	7	1	NO	0.36485	0.34338	0.21809	0.33282	0.46386	0.31169
8	7	7	8	8	1	NO	0.61244	0.62219	0.70988	0.63749	0.68703	0.76941
9	8	8	9	9	1	NO	0.99806	1.07846	0.94352	0.96660	1.15179	1.01174

Fig: Branch Data

Generator data

	Number of Bus	Name of Bus	Phase Cur A	Phase Cur B	Phase Cur C	Phase Ang A	Phase Ang B	Phase Ang C
1	1	1	0.66063	1.31339	1.31339	1.81	-178.40	61.60
2	2	2	1.63443	1.57982	1.58751	-0.01	-128.58	114.06
3	3	3	1.37241	1.49674	1.16817	2.12	-158.71	90.17

Fig: Generator Data

3.3.5 System with 3 phase balanced fault

Bus data

	Number	Name	Phase Volt A	Phase Volt B	Phase Volt C	Phase Ang A	Phase Ang B	Phase Ang C
1	1	1	0.00000	0.00000	0.00000	-11.52	-131.52	108.48
2	2	2	0.82952	0.82952	0.82952	-2.68	-122.68	117.32
3	3	3	0.91144	0.91144	0.91144	-7.37	-127.37	112.63
4	4	4	0.69289	0.69289	0.69289	-20.34	-140.34	99.66
5	5	5	0.74802	0.74802	0.74802	-21.89	-141.89	98.11
6	6	6	0.87450	0.87450	0.87450	-11.54	-131.54	108.46
7	7	7	0.84864	0.84864	0.84864	-12.70	-132.70	107.30
8	8	8	0.82762	0.82762	0.82762	-9.44	-129.44	110.56
9	9	9	0.73402	0.73402	0.73402	-20.01	-140.01	99.99

Fig: Bus Data

Branch data

	From Number	From Name	To Number	To Name	Circuit	Xfmr	Phase Cur A From	Phase Cur B From	Phase Cur C From	Phase Cur A To	Phase Cur B To	Phase Cur C To
1	1	1	4	4	1	NO	1.20293	1.20293	1.20293	1.20293	1.20293	1.20293
2	8	8	2	2	1	NO	1.56217	1.56217	1.56217	1.56217	1.56217	1.56217
3	3	3	6	6	1	NO	1.27339	1.27339	1.27339	1.27339	1.27339	1.27339
4	4	4	5	5	1	NO	0.67897	0.67897	0.67897	0.56653	0.56653	0.56653
5	4	4	9	9	1	NO	0.54275	0.54275	0.54275	0.42023	0.42023	0.42023
6	5	5	6	6	1	NO	1.16563	1.16563	1.16563	1.03087	1.03087	1.03087
7	6	6	7	7	1	NO	0.24558	0.24558	0.24558	0.37900	0.37900	0.37900
8	7	7	8	8	1	NO	0.68818	0.68818	0.68818	0.75138	0.75138	0.75138
9	8	8	9	9	1	NO	0.99319	0.99319	0.99319	1.08132	1.08132	1.08132

Fig: Branch Data

Generator data

	Number of Bus	Name of Bus	Phase Cur A	Phase Cur B	Phase Cur C	Phase Ang A	Phase Ang B	Phase Ang C
1	1	1	1.31339	1.31339	1.31339	-58.40	-178.40	61.60
2	2	2	1.56217	1.56217	1.56217	-7.17	-127.17	112.83
3	3	3	1.27338	1.27338	1.27338	-39.10	-159.10	80.90

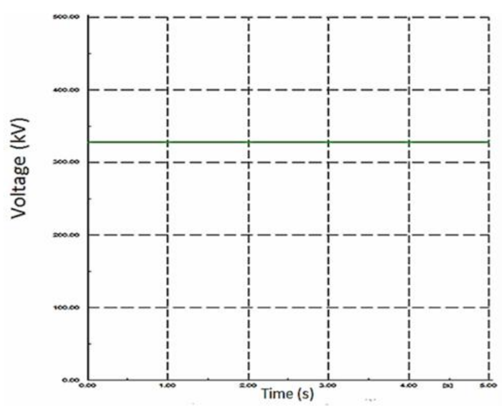
Fig: Generator Data

4. SIMULATION AND ANALYSIS

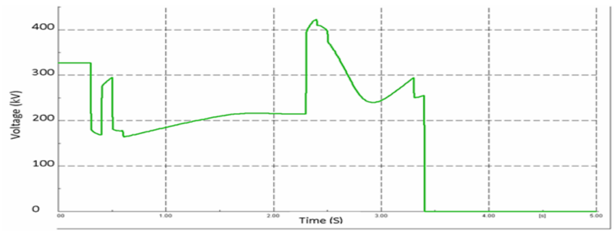
Since symmetrical components method includes many matrix operations, computer can be utilized to perform fault analysis in well-organized, effective, faster and logical means. The goal of including this part is to confirm the hand calculations found previously. In addition, the code can be used to accomplish this task where hand calculations can't handle a larger system and the analysis become difficult. Power world simulator was selected as the simulation tool in this project due to several reasons. Our background of Power world simulator was the main reason behind this choice. In addition, any code can be edited and modified easily to handle any future cases using the command edit window.

4.1 SIMULATION AND ITS STUDY

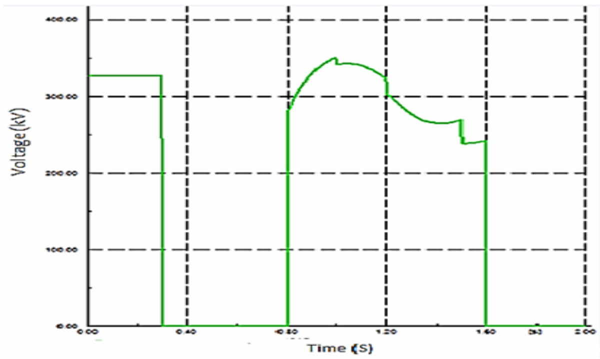
4.1.1 System study under steady state:



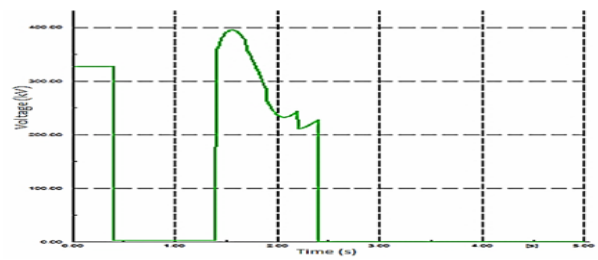
4.1.2 System study under single line to ground fault:



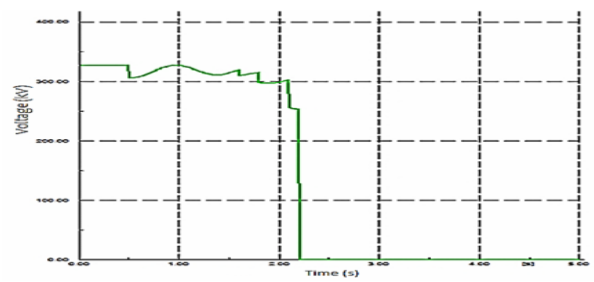
4.1.3 System under double line to ground fault:



4.1.4 System under line to line fault:



4.1.5 System under three phase fault:



V CONCLUSION

Based on the qualitative analysis of the obtained results, it can be concluded that the observed fault is ost probably a single phase to ground fault. After the power world simulation of fault, it was observed that the voltage and current waveforms were transient in nature in the initial period after the occurrence of faults. During the initial part of short circuit, the short circuit current was limited by sub transient reactance of synchronous machine and impedance of transmission line between the machine and point of fault. After that, it was limited by transient reactance of synchronous machine and impedance of line .Finally, the short circuit current settled down to steady state short circuit value limited by synchronous machines and line impedance. The negative and zero sequence components were present initially only and they disappeared after the circuit breaker cleared the fault.

When a fault occurred in a system there is a change in phase angle and generated voltage which can be observed in the above comparison

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