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Analysis of Symmetrical Fault in IEEE 14 Bus System for Enhancing Over Current Protection Scheme

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Abstract

The paper provides a simulation model of IEEE 14 bus system for short circuit studies and analysis of symmetrical fault using MiPower software. At the event of a fault occurrence, short circuit studies are performed to obtain current flow magnitude at different time intervals for a power system until steady state condition is achieved. The paper gives simulation result for the current which flows in different parts of the power system immediately after occurrence of a fault. The data obtained is further used to decide switch gear ratings and circuit breakers and also aids in setting and coordination of protective relays. Further the simulation result provides data regarding the contribution of different power system apparatus to the fault located at different buses in the power system and it gives an efficient, accurate and easy way to analyze symmetrical faults in a given power system.

Keywords*: Symmetrical Fault, Short Circuit and Load Flow Studies, Three Phase Fault*

1. Introduction

Modern power systems are extensive, highly interconnected systems comprising of number of generators along with transmission and distribution networks. Fault analysis form an integral part of power system analysis and it consists of determining the bus voltages and line currents during the occurrence of various types of faults. The impact of the faults is generally considered very critical for power system operation as it leads to interruption of power supply and destabilizes the whole system. Real-time detection of faults as well as isolation of faulty section is necessary prior to occurrence of major stability issues which may drive the system to unstable operation. Thus faults detection is of immense significance from operational and economic point of view. Power transfer through transmission system is extended over large distances covering huge areas to cater to distribution networks located even at distant places. There may be occurrence of symmetrical short circuit faults or flash over of lines due to lightning, insulation damage, etc. Statistics show [2] that almost fifty percent of power system faults occur in the transmission and distribution networks. Though the symmetrical faults are rare, they generally lead to most severe current to flow against which the power system must be protected. However, majority of the faults involved in power system are unsymmetrical types where it is necessary to compute, voltages and currents in the system under such unbalanced operating conditions by use of symmetrical components. The grouping of fault is in terms of Unsymmetrical and Symmetrical type where a fault involving all the three phases on the power system is known as symmetrical fault or three-phase fault while the one involving one or two phases is known as unsymmetrical fault. Single Line-to-ground, Line-to-line and Double line-to-ground faults are unsymmetrical faults [4]. The current paper is structured as follows: In Section 2, IEEE 14 bus system which is the power system model under study is presented. The problem formulation and system data

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is given in section 3. The simulation results and data are given in section 4 and conclusion in section 5.

2. Power System Model Under Study

A single line diagram of the IEEE 14-bus standard system taken from [1] is shown in figure 2.1. It consists of five synchronous machines with IEEE type-1 exciters, three of which are

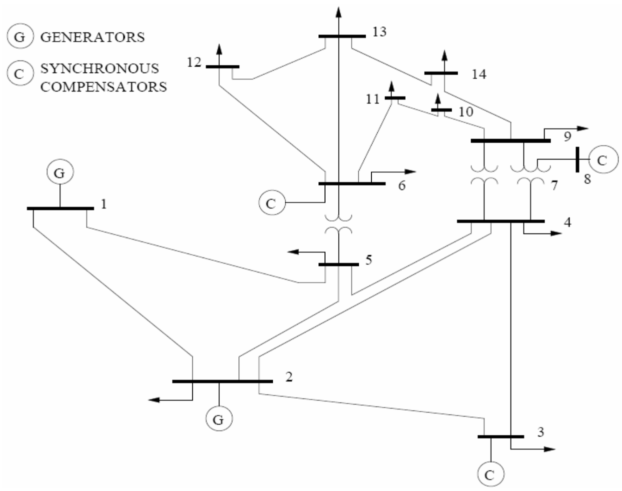

Figure 1. IEEE 14 Bus Standard System

Synchronous compensators used only for reactive power support. There are 11 loads in the system totaling 259 MW and 81.3 Mvar. The dynamic data for the generators exciters was selected from [1]. The system consists of 17 transmission lines and 11 loads.

3. Problem Formulation and System Data

a. Analysis of Symmetrical Fault

Electric systems occasionally experience short circuits which results in abnormally high currents. Over current protective devices should isolate faults at a given location safely, with minimal damage. The magnitudes of fault currents are usually estimated by calculations and the equipment is selected using the calculated results. In this paper, the symmetrical fault which is the most severe fault occurring in power system is simulated on the standard IEEE 14 bus system using MiPower software. The short-circuit analysis program analyzes the effect of 3-phase, line-to-ground, line-to-line, and line-to-line-to-ground faults on electrical distribution systems. The program calculates the total short circuit currents as well as the contributions of individual motors, generators, and utility ties in the system. Fault duties are in compliance with the latest editions of the ANSI/IEEE Standards (C37 series). When a symmetrical 3-phase fault occurs at the terminals of a synchronous generator, the resulting current flowing in the phases of the generator is represented as a transient DC component added on top of a symmetrical AC component. The total initial current is therefore typically 1.5 or 1.6 times the AC component alone. Three phase fault representation is given in figure 3.1 and its expression in terms of symmetrical component is also given in equations 3.1-3.3.

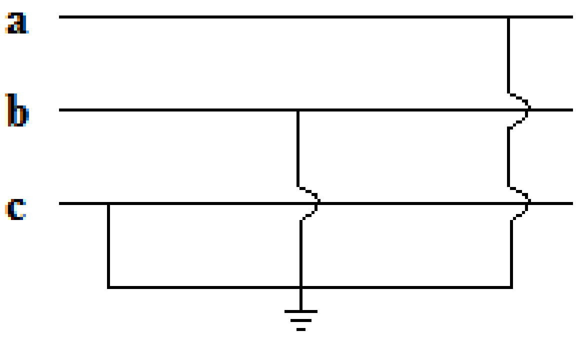

Figure 2. Representation of Three Phase to Ground Fault

b. Problem Formulation

The IEEE 14 bus system is simulated using MiPower software and load flow is conducted using N-R method to determine the pre fault voltage level at all the buses. After simulation, a symmetrical fault has been applied on bus 1 as given in the figure 4.1 to know the fault current withstanding capability of the circuit breaker located at bus 1 (Making and breaking Current value). Pre-fault voltage values, current values are the prerequisites for fault analysis.

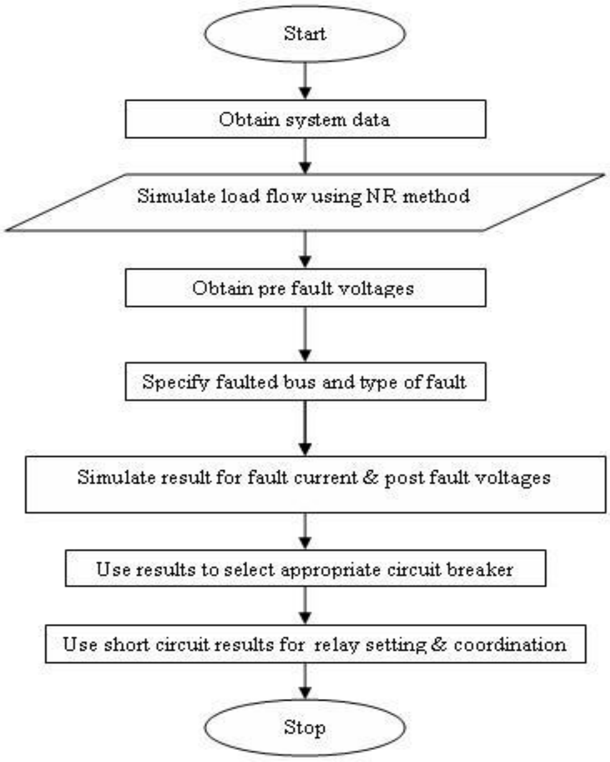

Figure 3. Execution Steps for Fault Evaluation, Circuit Breaker Choices and Relay Setting

Load flow analysis derived from pre-fault conditions provides voltage angle and magnitude data for individual bus, for designated load and generated real power and voltage state. The generator reactive power output and the reactive power flow for every bus can be logically calculated when the above data is available. The purpose of short circuit studies is to determine any or all of the following which includes: verification of protective device closing and latching capability, verification of protective device interrupting capability, protecting equipment from large mechanical forces (maximum fault kA), I^2t protection for equipment (thermal stress), selecting ratings or settings for relay coordination. The Execution steps for fault evaluation, circuit breaker choices and relay setting for over current protection at the event of occurrence of symmetrical fault is shown in figure 3.2.

c. System Data

The IEEE 14 bus system data for bus, transformers transmission lines and generators are given in the tables 3.1- 3.4 respectively.

Table 1. Bus Data

Bus	V(pu)	Δ(deg)	P_G	Q_G	P_L	Q_L
1	1.06	0	232.9	-19.5	0	0
2	1.045	-5.015	40	36.92	21.7	12.7
3	1.01	-12.821	0	20.69	94.2	19
4	1.0231	-10.601	0	0	47.8	-3.9
5	1.0262	-8.755	0	0	7.6	1.6
6	1.0697	-16.496	0	24	11.2	7.5
7	1.0526	-11.766	0	0	0	0
8	1.0823	-11.766	0	18.24	0	0
9	1.0548	-14.41	0	0	29.5	16.6
10	1.0504	-15.06	0	0	9	5.8
11	1.0569	-15.889	0	0	3.5	1.8
12	1.0543	-17.158	0	0	6.1	1.6
13	1.0503	-17.035	0	0	13.5	5.8
14	1.0348	-16.551	0	0	14.9	5

Where, buses 1-5 are at 220kV and 6-14 are at 132 kV. P_G and Q_G are real and reactive power generation and P_L and Q_L are real and reactive power of loads. Unit of active power is MW & reactive power is in MVAr.

Table 2. Transformer Data

From Bus	To Bus	Positive		Zero		TAP
		R p.u.	X p.u.	R p.u.	X p.u.	
5	6	0.00006	0.556	0.00006	0.556	0.93
4	7	0	0.048	0	0.048	0.98
4	9	0	0.556	0.00006	0.556	0.97

The breaker ratings from each bus is 15242 MVA (220kV) and breaker rating to each bus is 229MVA (132kV)

Table 3. Transmission Line Data

From	To	R_p(p.u)	X_p(p.u)	FB-MVA	TB-MVA
Bus1	Bus2	0.01938	0.05917	15242	15242
Bus2	Bus3	0.04699	0.19797	15242	15242
Bus2	Bus4	0.05811	0.17632	15242	15242
Bus1	Bus5	0.05403	0.2234	15242	15242
Bus2	Bus5	0.05695	0.17388	15242	15242
Bus3	Bus4	0.06701	0.17103	15242	15242

Bus4	Bus5	0.01355	0.04211	15242	15242
Bus7	Bus8	0	0.17615	229	229
Bus7	Bus9	0	0.11001	229	229
Bus9	Bus10	0.03181	0.0845	229	229
Bus6	Bus11	0.0949	0.1989	229	229
Bus6	Bus12	0.12291	0.25581	229	229
Bus6	Bus13	0.06615	0.13027	229	229
Bus9	Bus14	0.12711	0.27036	229	229
Bus10	Bus11	0.08205	0.19207	229	229
Bus12	Bus13	0.22092	0.1998	229	229
Bus13	Bus14	0.17093	0.34802	229	229

The Transmission line data gives the resistance and reactance values for the lines. FB MVA indicates the MVA rating from bus and TB MVA indicates the bus MVA values.

Table 4. Generator Data

From	Positive		Negative		Zero	
Bus	R p.u	X p.u.	R p.u.	X p.u.	R p.u.	X p.u.
1	0.001	0.007	0.001	0.007	0.001	0.007
2	0.002	0.011	0.002	0.011	0.002	0.01
3	0.007	0.130	0.006	0.22	0.006	0.1
6	0.002	0.162	0.002	0.22	0.002	0.1
8	0.001	0.095	0.001	0.2	0.001	0.1

Rating for circuit breakers (CB) in MVA connected to generators at buses 1-3 are 15242 and at bus 6-8 are 229 respectively.

4. Simulation and Result

a. Proposed Approach

The simulated result of symmetrical three phase fault applied on bus 1 for the IEEEE 14 bus system is shown in figure 4.1. The simulation result indicates the fault current in Amperes. Result provide in table 4.1 give the value of making and breaking current for the circuit breaker which are essential parameters to determine the correct rating of the device. Making is the initial peak current and the rated making capacity for a circuit breaker is determined by evaluating the max possible peak value of the short circuit current at the point of application. Breaking current is defined as the current required by the breaker to successfully open its contact at event of a fault to isolate the faulty section and these values are in the range of kA and the factor between the making and breaking current is 2.5. As per the industrial standards namely IEEE 37 series the fault level at 220kV is 40kA. It is observed that the given circuit breaker rating is not adequate to limit the short circuit current to a safe value and thus the circuit breaker rating is required to be modified for the current system as shown in figure 4.1 to the next higher level of 63 kA.

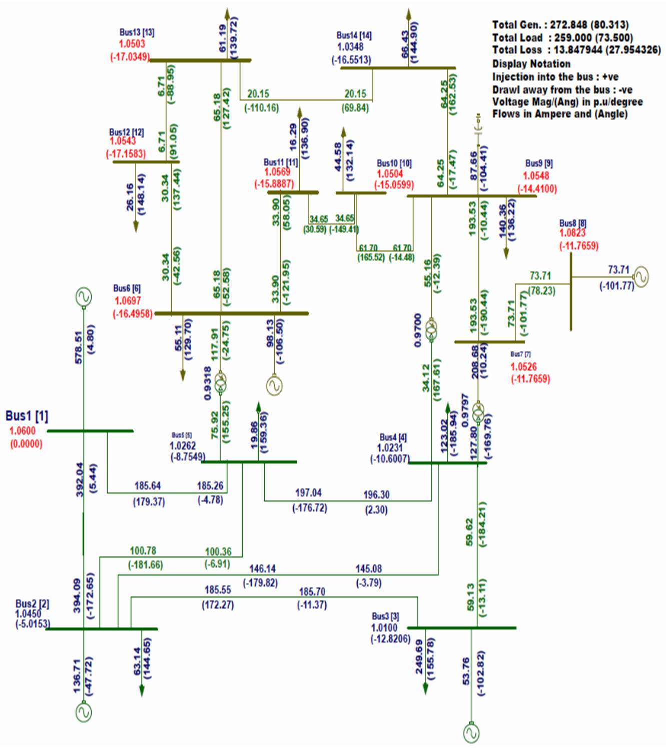

Figure 4. Simulation of Load Flow on IEEE 14 Bus System

It is also proposed to change the existing 220kV system to 400kV so that the circuit breaker ratings are adequate during the fault. The result for the Symmetrical three phase fault applied on bus 1 is given in the tables below:

Table 5. Fault Current (Amp/deg) at Bus 1

Sequence (1,2,0)		Phase (a,b,c)	
Magnitude	Angle	Magnitude	Angle
40635	-81.05	40635	-81.05
0	-90	40635	158.95
0	-90	40635	38.95
r/x ratio of the short circuit path: 0.1575			
peak asymmetrical short-circuit current*: 95368 amps			
*pascc = kx sqrt(2) x if , k=1.6595			

Table 4.1 indicates 3 phase momentary/peak current in amperes for half cycle and 1.5 to 4 cycle interrupting fault level for 220 kV bus systems. The simulation result thus indicates the making/peak and braking current capacity for circuit breaker selection at the faulted bus 1

Table 6. Fault MVA Bus 1

Sequence(1,2,0)	Phase (A,B,C)
Magnitude	Magnitude
15484	15484
0	15484
0	15484

The fault MVA for phase magnitude as observed from the result is same in all the three phases and for the sequence it will be reflected only in the positive sequence.

Table 7. Post Fault Voltages in P.U.

Name	Sequence Current (1,2,0)		Phase (A,B,C)		Line-Line Magnitude
	V	Angle	V	Angle	p.u. on L-L base
Bus1	0	-90	0	-90	0
	0	-90	0	150	0
	0	-90	0	30	0
Bus2	0.833	-1.43	0.833	-1.43	0.833
	0	-90	0.833	-121.4	0.833
	0	-90	0.833	118.57	0.833
Bus3	0.888	-1.65	0.888	-1.65	0.888
	0	-90	0.888	-121.6	0.888
	0	-90	0.888	118.35	0.888
Bus4	0.774	-1.5	0.774	-1.5	0.774
	0	-90	0.774	-121.5	0.774
	0	-90	0.774	118.5	0.774
Bus5	0.691	-1.17	0.691	-1.17	0.691
	0	-90	0.691	-121.2	0.691
	0	-90	0.691	118.8	0.691
Bus6	0.902	-0.82	0.902	-0.82	0.902
	0	-90	0.902	-120.8	0.902
	0	-90	0.902	119.18	0.902
Bus7	0.813	-1.02	0.813	-1.02	0.813
	0	-90	0.813	-121.0	0.813
	0	-90	0.813	118.98	0.813
Bus8	0.934	-0.28	0.934	-0.28	0.934
	0	-90	0.934	-120.3	0.934
	0	-90	0.934	119.72	0.934
Bus9	0.827	-0.53	0.827	-0.53	0.827
	0	-90	0.827	-120.5	0.827
	0	-90	0.827	119.47	0.827
Bus10	0.84	-0.54	0.84	-0.54	0.84
	0	-90	0.84	-120.6	0.84
	0	-90	0.84	119.46	0.84
Bus11	0.87	-0.64	0.87	-0.64	0.87
	0	-90	0.87	-120.7	0.87
	0	-90	0.87	119.36	0.87
Bus12	0.897	-0.85	0.897	-0.85	0.897
	0	-90	0.897	-120.9	0.897
	0	-90	0.897	119.15	0.897
Bus13	0.891	-0.75	0.891	-0.75	0.891
	0	-90	0.891	-120.8	0.891
	0	-90	0.891	119.25	0.891
Bus14	0.855	-0.61	0.855	-0.61	0.855
	0	-90	0.855	-120.6	0.855
	0	-90	0.855	119.39	0.855

As observed from the result of post fault voltages during the fault, voltage at bus 1 is zero and voltage drop is reflected in the neighboring buses.

Table 8. Fault Contribution From Shunt Connection

From	Current (Amps/Degree)				MVA
Name	Sequence (1,2,0)		Phase (A,B,C)		Phase (A,B,C)
	I	Angle	I	Angle	Magnitude
Bus1	36371	98.13	36371	98.13	13859
	0	-90	36371	-21.87	13859
	0	-90	36371	-141.9	13859
Bus2	3731	106.82	3731	106.8	1422
	0	-90	3731	-13.18	1422
	0	-90	3731	-133.2	1422

The elements that contribute current to a short circuit are generators, synchronous condensers, delta - star grounded transformers. Details of fault current contribution are given in table 4.4 and shown in figure 4.1.

Table 9. Three Phase Fault Level

Name	Bus kV	3PH-fMVA	Fault I
	NOMINAL		kA
Bus1	220	15483.6	40.635
Bus2	220	0.3	0.001
Bus3	220	0.3	0.001
Bus4	220	0.3	0.001
Bus5	220	0.3	0.001
Bus6	132	0.2	0.001
Bus7	132	0.2	0.001
Bus8	132	0.2	0.001
Bus9	132	0.2	0.001
Bus10	132	0.2	0.001
Bus11	132	0.2	0.001
Bus12	132	0.2	0.001
Bus13	132	0.2	0.001
Bus14	132	0.2	0.001

Table 4.5 gives simulation result after application of three phase fault, the fault current level at bus 1 is 40.635kA.This analysis helps to design and provide setting for circuit breakers and relay coordination leading to proper power system protection. Figure 4.2 gives the detailed result of short circuit level at the faulted bus 1 and various elements contributing towards the fault. Since the type of fault is symmetrical and circuit breaker rating fixed to require interrupting capacity, the relays placed at the faulted bus are both over current type as shown in figure 4.2. Settings for the current transformer (CT) and over current relays R1and R2 based on the simulation results obtained are given in table 4.6 .The primary current settings of the CT are obtained by calculating the current under normal load flow conditions. The secondary setting are decided based upon the type of protection scheme that is implemented, the element type as well as the nature of fault. The plug setting indicates the pick up current of the relay required for sensing the fault and initiate the tripping of the circuit breaker for clearing the fault. Simulation result of the relay coordination intimates the time dial settings (TDS) and simultaneously gives the calculation of the operating time for closing fault current taking into account the pick up

setting as in table 4.7. On the occurrence of fault on bus 1 R2 provides the primary protection and if it fails then R1will operate as a back up protection based upon the discrimination time. Discrimination time is the difference between time of operation (TOP) of R1 and R2. As per calculation done by the software it is 0.3228 sec and is within prescribed limits. Figure 4.4 depicts the waveform for over current protection scheme using relays R1 and R2.

Table 10. Relay Setting

Relay	CT -P (A)	CT-S (A)	Plug Setting (%)	Plug setting (prim) (A)	Plug setting sec) (A)
R1	600	5	130	780	6.5
R2	400	5	130	520	6.5

Graphical representation obtained from simulation of three phase fault on bus 1 of the model under study is given in figure 4.3.

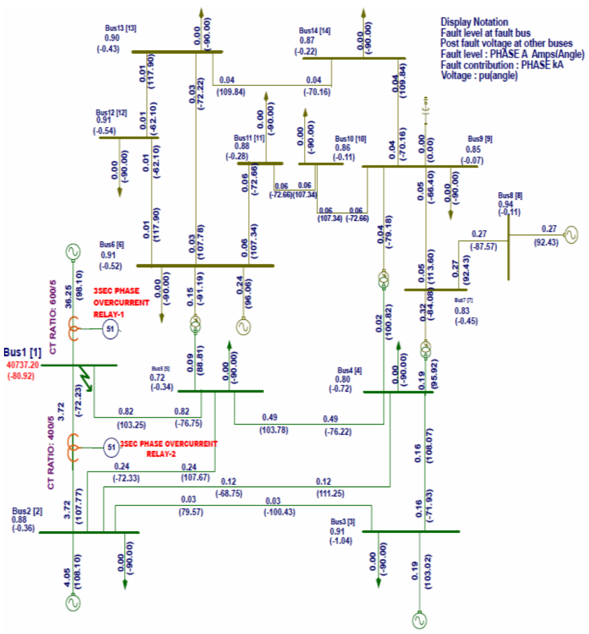

Figure 5. Simulation of Three Phase Symmetrical Fault and Over Current Relay Coordination on IEEE 14 Bus System

Table 11. Relay Coordination

Relay	TDS	Close in fault current (amps)	TOP for closing in fault (sec)	Remote bus fault current (amps)	Time for remote fault (sec)
R1	0.19	36246.46	0.4381	36246.46	0.4381
R2	0.05	37043.48	0.1153	Will not act as back up	

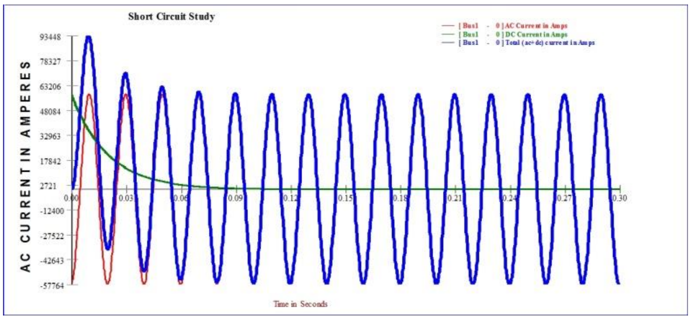

Figure 6. Waveform for Three Phase Symmetrical Fault with Dc Component

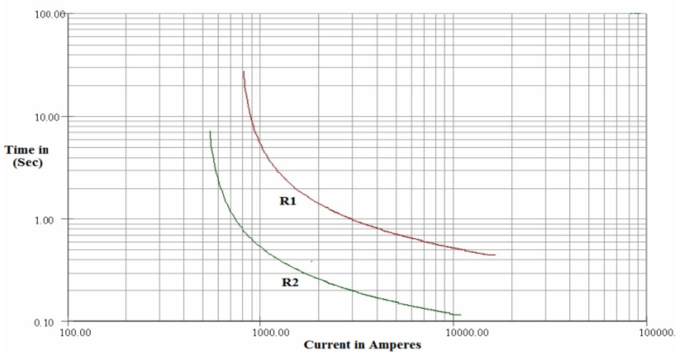

Figure 7. Phase Relay Coordination Curve of Fault at Bus 1(220kv)

5. Conclusion

This paper presents simulation of IEEE 14 bus system using MiPower software for symmetrical three phase fault analysis. The result obtained by applying a three phase fault on bus 1 is used for circuit breaker selection and over current relay setting which helps in enhancing system operation, protection and reliability. In comparison with simulation studies done earlier with other software tools, the result of this paper is better as it provides detailed information for fault current, fault MVA, post fault voltages at all the buses, values of making and breaking current, contribution of various elements towards the fault. Further, it gives complete system behavior during occurrence of three phase fault which is considered as rarest but severest of all the faults occurring in a given power system.

Appendix

System Data: All data are in p.u. unless specified otherwise
Base MVA: 100
Transformers Rating:
T_1: 132/220kV, 150 MVA, Δ-y grounded % Z = 0.556 p.u. tap 1-45, set tap 13, NT 23
T_2: 132/220kV, 150 MVA, Δ -y grounded % Z = 0.556 p.u. tap 1-21, set tap 9, NT 11
T_3: 132/220kV, 150 MVA, Δ -y grounded % Z = 0.556 p.u. tap 1-38, set tap 17, NT 20.

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