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The Use of Three-Phase Fault Analysis for Rating Circuit Breakers on Nigeria 330 kV Transmission Lines

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Abstract: Fault studies play a significant role in the power system security for the supply and generation of electrical energy to end-users. This research work focuses on the analysis and simulation of 3 kV" fault phenomenon to determine the voltage magnitude and fault current magnitude in the test system. The test system is the Nigeria 28-bus, 330 kV Transmission System. The 28-bus system is simulated using MATLAB-based programme and the maximum current magnitude obtained is used to determine an appropriate value of the circuit breaker rating for all the linesin the 330 kV power system. This research therefore, suggests the level of protection to be applied on Nigeria 330 kV power lines with the aim of improving system security as the information gained from this study helps in the setting of relay. The study revealed the abnormally high magnitude of current that flows through the powerline to the point of fault and recorded the highest value of 6.4376 kA (36.796 pu) through the line 4-3 (Jebba GS-Jebba TS) when Jebba GS is faulted.

Key words: Power system security, simulation, three-phase, circuit breaker, maximum current magnitude

INTRODUCTION

Modern life and civilization depend, to a great deal, on easy access to electricity. So, what happens when disruptions occur, when the electric grid is no longer reliable and there is no longer easy access to electricity? Moreover, the erratic and epileptic state of power in Africa, especially Nigeria is another strong drive towards this research. In Nigeria, the overall transmission and distribution losses due to system disturbance are in the mega range of 30-40%. The transmission losses calculated to be approximately 10.05% of the energy fed into the grid, clearly show that majority of the outages that occur in the Nigerian Electricity Supply System are the underlying problem in the transmission network. Further analysis of the causes of grid failures-both partial and total from 1987-2009, revealed that: out of total faults (partial and total) of 276 grid-failures experienced in this period, about 78.6% were caused by transmission faults (that is 217) while the remaining were caused by faults from the generating units. These disturbances could lead to abnormal system conditions such as short circuits, overloads and open circuits. Fault studies form an important part of power system analysis. Short circuits which are also referred to as faults are of the greatest concern because they could lead to damage to equipment or system elements and other operating problems including voltage drops, decrease in frequency, loss of synchronism and complete system collapse (Abdulkareem *et al*., 2014). Other effects of faults on power system generally include arcing and burning at the short-circuit locations, flowing of short-circuit current from various sources to the short-circuit location and overheating and mechanical stress of all components carrying short-circuit currents.There is therefore, a need for fault current evaluation on a power system because the circuit breaker rating to be installed for interruption of the short-circuit currentgreatly depends on the values of the fault currents. Faults that occur on transmission lines are broadly classified into three-phase, short-circuit and unsymmetrical faults. A fault involving all the threephasesof the power lines is known as symmetrical fault or three-phase fault while the one that involves one or two phases is known as unsymmetrical fault. Single line-to-ground, line-to-line and doubleline-to-ground faults are unsymmetrical. A three-phase short-circuit occurs rarely but it is most the severe of faults involving largest currents. For this reason, the circuit breaker rating in MVA breaking capacity is determined based on 3-phase fault MVA calculation. It should be noted that three-phase fault inflicts greatest damage to the power system, except in a situation where a single line-to-ground

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fault is very close to a solidly grounded generator's terminals. In this instance, the severity of single line-to-ground fault is greater than that of 3-phase balanced fault (Abdulkareem *et al*., 2014). As discussed above, fault studies form an important part of power system analysis. The problem consists of determining bus voltages and line currents during various types of faults. In this work, the impedance bus matrix is employed for building algorthim for the symmetrical computation of the voltages at all the 28 buses and the 33 line currents of the test system during a three-phase fault. MATLAB programme was developed with the Graphical User Interface (GUI) to compute these bus voltages and line currents.

MATERILAS AND METHODS

The methodology adopted for this study incudes load-flow analysis of the test system using the Power Word Simulator (PWS) software to determine the voltage magnitude and angle in degrees at each bus in the test system, problem formulation (three-phase equations) and result analysis of three-phase simulation on the test system at every bus for all the 28 buses using MATLAM in GUI environment. This is followed by the analysis of line current magnitudes obtained under GUI for the circuit breaker rating selection.

Load-flow analysis of the test system: In short-circuit studies, it is normally required to analyse the voltages and currents at steady-state in order to have the knowledge of their values before the occurrence of the fault. The 330 kV network test system was thereforeanalysed for load-flow using the Power World Simulator.The one-line diagram of the 28 buses was modeledin the edit mode of power world simulator. The load-flow simulation of the test system was performed usingNewton-Raphson iterative method available in the run mode of PWS to obtain the bus voltages, phase angles, line flows and losses after inputting line impedance data, load and generation schedules into the dialogue box of PWS in the edit mode. Figure 1 shows the simulation mode of the Test Grid Model.

Problem formulation (short-circuit equations): To calculate the fault currents for the three-phase faults in the 28-bus test grid, the system is modeled by the positive sequence network. This is because in static power system components like transformer and transmission lines, the sequence impedance offered by the system is the same for positive and negative currents (Hadi, 2007). The equations relating the sequence quantities are as follows:

$$V_{bus}^{0} = -\left[Z_{bus}^{0}\right]I_{bus}^{0} \tag{1}$$

$$V_{bus}^{1} = E_{bus} - \left[Z_{bus}^{1}\right]I_{bus}^{1} \tag{2}$$

$$V_{bus}^{2} = -\left[Z_{bus}^{2}\right]I_{bus}^{2} \tag{3}$$

where, V_{bus}^{0}, V_{bus}^{1} and V_{bus}^{2} are the phase terminal voltage of the zero, positive and negative sequence networks, respectively. Only the positive sequence network has a voltage source as shown in Eq. 2. For simplicity, the pre-fault currents are neglected or zero (Kothari and Nagrath, 2008) and all the pre-fault bus voltages are assumed to be 1 pu.

Equation for short-circuit studies: Using Eq. 1-3 the equation for short citcuit studies are developed as follow:

$$V_{bus}^{0}, V_{bus}^{2}, I_{bus}^{0} \text{ and } I_{bus}^{2}$$

are zero:

$$V_k^1 = E - \left(Z_k^1 I_1^1 + Z_k^1 I_{k2}^1 + \ldots + Z_k^1 I_k^1 + \ldots + Z_{kn}^1 I_n^1\right) \tag{4}$$

Since, all currents except at the faulted bus, i.e,. $I_k{}^1$ are zero. Therefore:

$$V_k^1 = E - Z_{kk}^1 I_k^1 \tag{5}$$

Let Z_f be the fault impedance, then:

$$V_k^1 = I_k^1 Z_f \tag{6}$$

The network is then modified to correspond to the desired representation for short-circuit studies. Being a linear network of several voltage sources, further calculations are computed by applyingof Thevenin's theorem (Gupta, 2008) to give:

$$I_k^1 = \frac{E}{Z_{kk}^1 + Z_f} \tag{7}$$

Equation 7 gives the short-circuit fault current in $I_k{}^1$ per unit:

$$I_k^1 = \frac{E}{Z_{kk}^1 + Z_f}$$

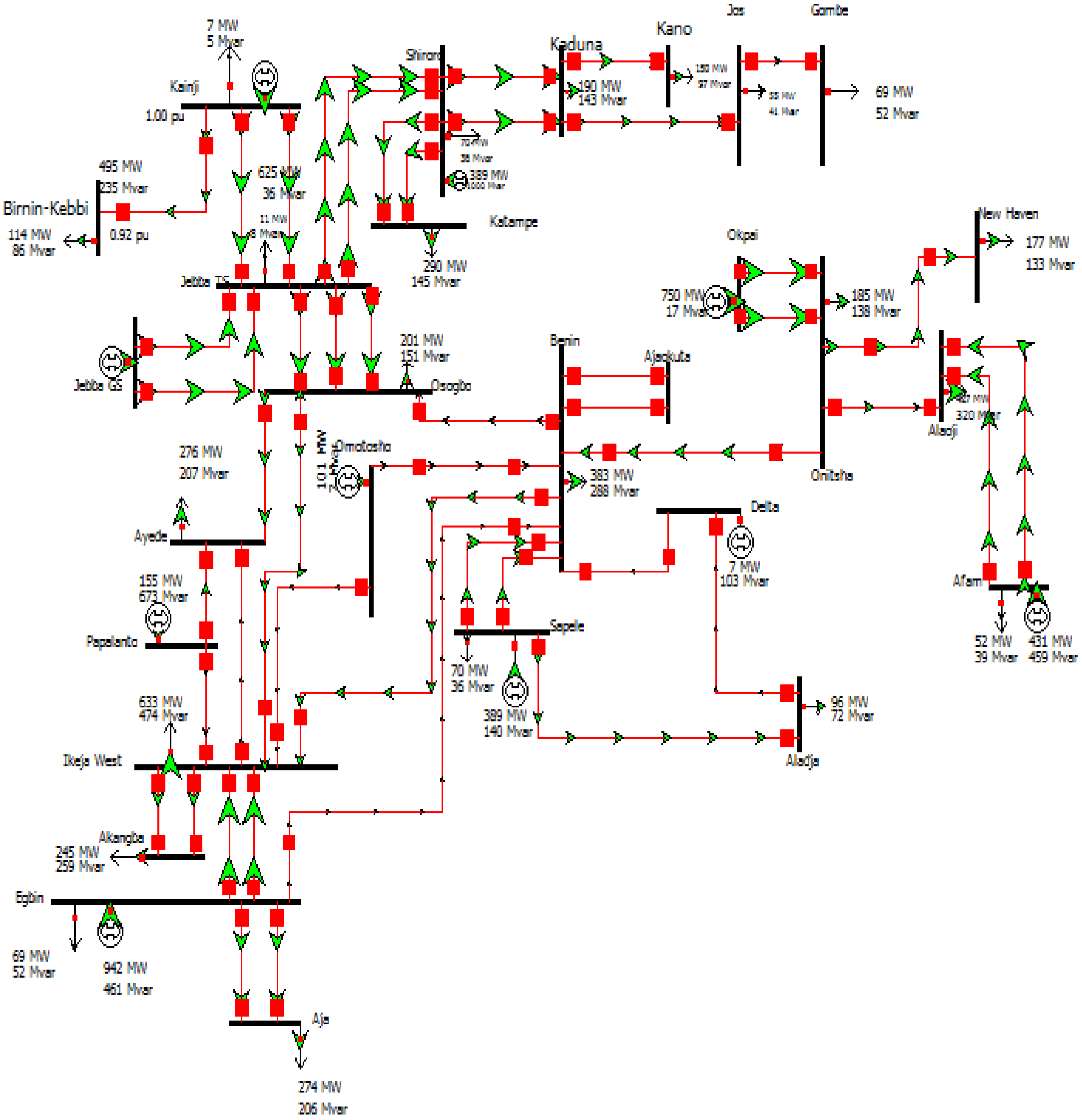

Fig. 1: Simulation mode of the 330 kV transmission grid model

The voltage at the ith bus is given as:

$$V_i^1 = E - Z_{ik}^1 I_k^1 = E\left(1 - \frac{Z_{ik}^1}{Z_{kk}^1 + Z_f}\right)$$

for $i = 1, 2, \ldots, n$

Where:

V_i^1 = Positive sequence bus voltage for bus k
V_k^1 = Positive sequence bus current for bus k
V_{kk}^1 = Positive sequence bus impedance between buses k and n
E = Induced e.m.f. under load condition
Z_f = Fault impedance

Simulation software: The MATLAB code used to solve the problem statement in this project starts by identifying the system input arguments. These variables are manly positive and zero sequence impedances for Nigeria 330 kV transmission system branches. This step is necessary to form the system impedance data; making use of the PHCN data (positive and zero sequence impedances) for Nigeria 330 kV transmission line. This is followed by a complete and unambiguous set of computational steps in a particular sequence performed for three-phase using MATLAB codes. The flowchart of the algorithm developed for obtaining the result is shown in Fig. 2.

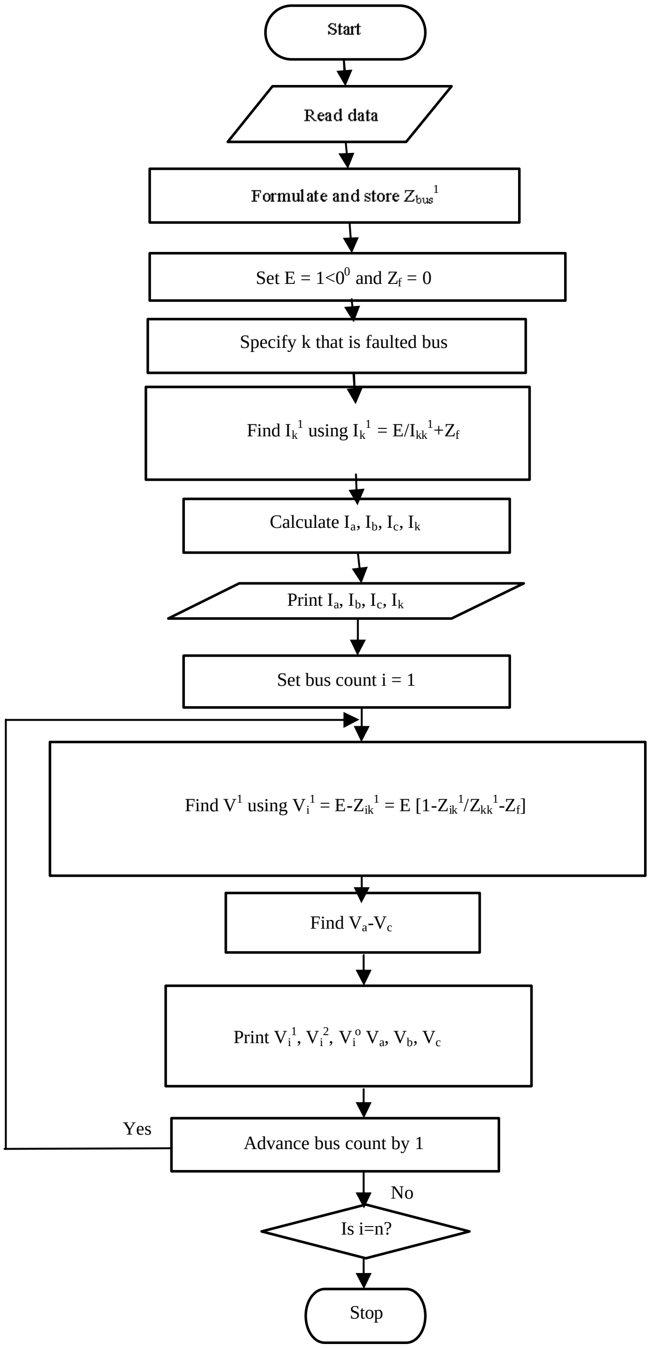

Fig. 2: Flowchart for 3-phase symmetrical fault

RESULTS AND DISCUSSION

The results of load-flow solution of Newton-Raphson (N-R) in PWS and simulation results of the three-phase short-circuit analysis performed on the 330 kV Nigerian 28 bus systems (test system) for determining the maximum fault current magnitude are presented and discussed in here. Therecommended ratings of thecircuit breakers for the 33 lines of the 330 kV 28 bus system are also presented and discussed.

Load-flow solution of N-R: Table 1 shows the load-flow solutions obtained for 330 kV Nigerian 28 buses. The voltage magnitude (V) of ±10% ($V_{min} \leq V \leq V_{max}$, i.e., 313.5 is

Table 1: Result of load-flow studies before fault analysis

Bus No.	Bus name	Volt (kV)	Angle (Deg)	Load MW	Load Mvar	Gen MW	Gen Mvar
1	Kainji	330.00	8.53	7.000	5.200	624.700	-19.720
2	B/Kebbi	303.04	2.21	114.500	85.900	0.000	0.000
3	Jebba TS	329.97	4.96	11.000	8.200	0.000	0.000
4	Jebba GS	330.00	5.25	0.000	0.000	495.000	-67.790
5	Oshogbo	325.30	1.79	201.200	150.900	0.000	0.000
6	Ayede	320.54	-2.17	275.800	206.800	0.000	0.000
7	Papalanto	330.00	-1.60	0.000	0.000	154.800	443.350
8	Ikeja-West	320.46	-1.86	633.200	474.000	0.000	0.000
9	Akangba	312.40	-3.01	244.700	258.500	0.000	0.000
10	Egbin	330.00	0.00	68.900	51.700	491.340	528.580
11	Aja	323.67	-1.26	274.000	205.800	0.000	0.000
12	Omotosho	330.00	10.96	0.000	0.000	100.600	-15.870
13	Benin	327.03	9.82	383.300	287.500	0.000	0.000
14	Ajaokuta	332.86	9.47	13.800	10.300	0.000	0.000
15	Sapele	330.00	10.94	20.600	15.400	190.300	127.230
16	Delta	330.00	14.75	0.000	0.000	670.000	-0.130
17	Aladja	327.90	12.35	96.500	72.400	0.000	0.000
18	Onitsha	318.31	17.38	184.600	138.400	0.000	0.000
19	Okpai	330.00	18.79	0.000	0.000	750.000	45.900
20	New Haven	303.58	14.27	177.000	133.400	0.000	0.000
21	Afam	330.00	12.86	52.500	39.400	431.000	414.680
22	Alaoji	319.93	13.10	427.000	320.200	0.000	0.000
23	Shiroro	330.00	-7.81	70.300	36.100	388.900	569.650
24	Katampe	320.65	-11.10	290.100	145.000	0.000	0.000
25	Kaduna	304.68	-13.15	193.000	144.700	0.000	0.000
26	Kano	256.05	-24.80	220.600	142.900	0.000	0.000
27	Jos	270.33	-21.94	70.300	52.700	0.000	0.000
28	Gombe	239.15	-29.71	130.600	97.900	0.000	0.000

considered as the acceptable voltage limit for 330 kV transmission lines (Caven, 1991). The disproportionate voltage magnitude in power flows as recorded in some of the system transmission lines are as shown highlighted in Table 1.

Circuit breaker ratings: The circuit breakers are the main protection elements of the power system. These items need to open when fault circuit flows through the circuit. Faults on a power system resulting in high currents and also possible loss of synchronism must be removed in the minimum of time. Automatic means, therefore are required to detect abnormal currents and voltages and when detected to open the appropriate circuit breakers. A circuit breaker should be able to carry the rated current continuously at the nominal voltage and also be able to withstand the large short-circuit that flows during the first cycle after a fault occurs. The circuit breaker depends on the values of fault currents in order for it (i.e., the circuit breaker) to interrupt a large short-circuit current (called its momentary rating) and also be able to interrupt a large short-circuit current called its interrupting rating.

Selection of circuit breaker ratings: Two factors are of utmost importance for the selection of circuit breakers. These are:

- The maximum instantaneous current that a breaker must withstand
- The total current when the breaker contacts part

However, the instantaneous current following a fault will also contain the dc component. In a high power circuit breaker selection, the subtransient current is multiplied by a factor of 1.6 to determine the rms value of the current which the circuit breaker must withstand. This current is called the momentary current. The interrupting current of a circuit breaker is lower than the momentary current and will depend upon the speed of the circuit breaker.

The maximum symmetrical interrupting current of the circuit breaker was obtained by subjectingeach bus of the test system (i.e., buses 1-28) to a bolted impedance three-phase fault and simulated using MATLAB software in Graphical User Interface (GUI). Table 2-8 show the voltage magnitude and their angles in degrees when a three-phase fault was simulated at each of buses 1-28. The three-phase short-circuit MVA which determines the rating of the circuit breaker to be installed, was calculated as follows:

$$\text{MVAsc (three-phase)} = \sqrt{3V_LI_{SC}} \qquad (8)$$

The interrupting rating of a circuit breaker is specified in MVA (Eq. 8) and the interrupting MVA equals $\sqrt{3}$ times the kilovolts (kV) of the bus to which the breaker is connected times the current which the breaker must interrupt which should belower than the momentary current.The momentary rating is about 1.6 times the interrupting rating because the former includes the effect of the DC component of the transient short-circuit current. In the short-circuit MVA studies, a base current

Table 2: Voltage magnitude and angles for faults on buses 1-4

	Bus 1		Bus 2		Bus 3		Bus 4	
Bus	Voltage Mag	Voltage angle	Voltage Mag	Voltage angle	Voltage Mag	Voltage angle	Voltage Mag	Voltage angle
1	0.0000	0.00000	0.8692	-0.8475	0.4581	-3.7954	0.5043	-3.49620
2	5.48E-18	-90.00000	0.0000	-0.5834	0.4407	-3.7954	0.4851	-3.49620
3	0.5044	-2.01830	0.9546	-0.5870	0.0000	0.0000	0.0817	-3.46130
4	0.5258	-2.15840	0.9599	-0.2712	0.0396	-7.4733	0.0000	0.00000
5	0.7774	-0.76370	0.9659	-0.2131	0.5662	-0.5700	0.6004	-0.69280
6	0.8094	-0.63600	0.9416	-0.1958	0.6612	-0.6286	0.6852	-0.68060
7	0.8333	-0.60420	0.9507	-0.1861	0.7018	-0.6538	0.7231	-0.68710
8	0.8411	-0.58190	0.9504	-0.1861	0.7185	-0.6496	0.7384	-0.67590
9	0.7979	-0.58190	0.9015	-0.1436	0.6816	-0.6496	0.7004	-0.67590
10	0.9627	-0.52700	1.0351	-0.1436	0.8814	-0.7510	0.8946	-0.73320
11	0.9288	-0.52700	0.9986	-0.0688	0.8504	-0.7510	0.8631	-0.73320
12	1.0344	-0.25620	1.0672	-0.0900	0.9974	0.3682	1.0034	-0.35810
13	0.9808	-0.28790	1.0332	-0.0900	0.9221	-0.3426	0.9316	-0.34800
14	1.0203	-0.28790	1.0747	-0.0778	0.9592	-0.3426	0.9691	-0.34800
15	1.0067	-0.29240	1.0426	-0.0763	0.9663	-0.4249	0.9729	-0.41240
16	1.0076	-0.28700	1.0428	-0.0771	0.9680	-0.4171	0.9744	-0.40480
17	1.0043	-0.28970	1.0397	-0.0057	0.9644	-0.4210	0.9709	-0.40860
18	0.9472	0.15390	0.9834	-0.0057	0.9070	0.4832	0.9134	-0.41760
19	1.0036	0.15390	1.0420	-0.0057	0.9609	0.4832	0.9678	0.41760
20	0.9080	0.15390	0.9427	-0.0892	0.8694	0.4832	0.8757	0.41760
21	1.0358	-0.46770	1.0477	-0.0748	1.0222	-0.8620	1.0245	-0.80050
22	0.9751	-0.36620	0.9900	-0.3304	0.9581	-0.6498	0.9609	-0.60730
23	0.8414	-1.30150	1.0143	-0.3304	0.6473	-2.0942	0.6787	-2.00190
24	0.7957	-1.30150	0.9592	-0.3304	0.6121	-2.0942	0.6419	-2.00190
25	0.7236	-1.30150	0.8723	-0.3304	0.5566	-2.0942	0.5837	-2.00190
26	0.6018	-1.30150	0.7254	-0.3304	0.4629	-2.0942	0.4855	-2.00190
27	0.6771	-1.30150	0.8162	-0.3304	0.5209	-2.0942	0.5462	-2.00190
28	0.6162	-1.30150	0.7428	-0.3304	0.4740	-2.0942	0.4971	-2.00190

Table 3: Voltage magnitude and angles for faults on buses 5-8

	Bus 5		Bus 6		Bus 7		Bus 8	
Bus	Voltage Mag	Voltage angle	Voltage Mag	Voltage angle	Voltage Mag	Voltage angle	Voltage Mag	Voltage angle
1	0.8585	-1.3706	0.9374	-0.8216	0.9420	-0.7890	0.9212	-0.9233
2	0.8585	-1.3706	0.9016	-0.8216	0.9061	-0.7890	0.8861	-0.9233
3	0.7083	-1.5298	0.8481	-0.9141	0.8563	-0.8779	-0.8195	-1.0171
4	0.7225	-1.5789	0.8573	-0.9378	0.8652	-0.9004	0.8297	-1.0464
5	0.0000	0.0000	0.4134	-0.9825	0.4377	-0.9464	0.3289	-0.9395
6	0.2639	-1.6418	0.0000	0.0000	0.1653	-1.1825	0.1017	-0.9381
7	0.3492	-1.6909	0.2310	-1.7015	0.0000	0.0000	0.0341	-0.5237
8	0.3902	-1.6412	0.3457	-1.4945	0.2377	-1.3832	0.0000	0.0000
9	0.3701	-1.6412	0.3279	-1.4945	0.2255	-1.3832	1.11E-16	0.0000
10	0.6638	-1.8557	0.6442	-1.8558	0.5777	-2.1122	0.4266	-3.1240
11	0.6404	-1.8557	0.6221	-1.8558	0.5573	-2.1122	0.4116	-3.1240
12	0.8985	-0.7922	0.9215	-0.6745	0.9046	-0.7060	0.8553	-0.8534
13	0.7648	-0.6773	0.8112	-0.6390	0.7885	-0.6574	0.7161	-0.7539
14	0.7955	-0.6773	0.8438	-0.6390	0.8202	-0.6574	0.7450	-0.7539
15	0.8583	-0.9314	0.8902	-0.8155	0.8746	-0.7120	0.8249	-1.0808
16	0.8621	-0.9121	0.8934	-0.7991	0.8781	-0.8534	0.8294	-1.0576
17	0.8577	-0.9217	0.8892	-0.8073	0.8739	-0.8623	0.8248	-1.0692
18	0.7990	1.4333	0.8307	1.0782	0.8152	1.2840	0.7657	1.8171
19	0.8465	1.4333	0.8801	-1.0782	0.8637	1.2840	0.8113	1.8171
20	0.7659	1.4333	0.7963	-1.0782	0.7814	1.2840	0.7340	0.8171
21	0.9863	-1.9984	0.9970	-1.6686	0.9918	-1.8289	0.9752	-2.3568
22	0.9130	-1.4971	0.9264	-1.2573	0.9198	-1.3736	0.8990	-1.7630
23	0.9198	-0.9311	0.9734	-0.5721	0.9766	-0.5501	0.9624	-0.6403
24	0.8698	-0.9311	0.9206	-0.5721	0.9236	-0.5501	0.9102	-0.6403
25	0.7910	-0.9311	0.8371	-0.5721	0.8399	-0.5501	0.8277	-0.6403
26	0.6579	-0.9311	0.6962	-0.5721	0.6985	-0.5501	0.6884	-0.6403
27	0.7402	-0.9311	0.7834	-0.5721	0.7859	-0.5501	0.7745	-0.6403
28	0.6736	-0.9311	0.7129	-0.5721	0.7152	-0.5501	0.7049	-0.6403

of 0.174.9546 kA and a recovery Voltage (V_L) (which is approximately equal to the system voltage (i.e., 330 kV)) are computed together with the various maximum fault currents calculations on each of buses 1-28 as obtained in

Table 4: Voltage magnitude and angles for faults on buses 9-12

	Bus 9		Bus 10		Bus 11		Bus 12	
Bus	Voltage Mag	Voltage angle	Voltage Mag	Voltage angle	Voltage Mag	Voltage angle	Voltage Mag	Voltage angle
1	0.9785	-0.5689	0.9557	-0.6770	1.0018	-0.4362	1.0168	-0.2519
2	0.9412	-0.5689	0.9193	-0.6770	0.9636	-0.4362	0.9781	-0.2519
3	0.9210	-0.6640	0.8806	-0.7415	0.9624	-0.5416	0.989	-0.2830
4	0.9276	-0.6744	0.8806	-0.7617	0.9674	-0.5446	0.9932	-0.2885
5	0.6288	-0.9680	0.5097	-0.6897	0.7510	-0.9737	0.8304	-0.3263
6	0.4865	-1.2609	0.3497	-0.7122	0.6515	-1.2535	0.7882	-0.3441
7	0.4515	-1.3683	0.3069	-0.6936	0.6324	-1.3476	0.7892	-0.3488
8	0.4316	-1.4563	0.2839	-0.7311	0.6197	-1.4087	0.7856	-0.3528
9	0.0000	0.0000	0.2693	-0.7311	0.5878	-1.4087	0.7452	-0.3528
10	0.7032	-1.6276	0.0000	0.0000	0.5116	-2.2828	0.8912	-0.5827
11	0.6785	-1.6276	2.22E-16	178.4710	0.0000	-0.5921	0.8598	-0.5827
12	0.9524	-0.5749	0.8692	-0.7757	0.9692	-0.6241	0.0000	0.0000
13	0.8617	-0.5945	0.7191	-0.5050	0.8775	-0.6241	0.7320	-0.3247
14	0.8963	-0.5945	0.7481	-0.5050	0.9128	-0.6849	0.7615	-0.3247
15	0.9249	-0.6938	0.8269	-0.9255	0.9358	-0.6715	0.8356	-0.7880
16	0.9274	-0.6802	0.8313	-0.9062	0.9381	-0.6782	0.8399	-0.7722
17	0.9235	-0.6870	0.8267	-0.9158	0.9342	0.5928	0.8354	-0.7801
18	0.8652	0.7264	0.7681	1.9480	0.8760	0.5928	0.7772	1.9469
19	0.9167	0.7264	0.8139	1.9480	0.9281	0.5928	0.8235	1.9469
20	0.8294	0.7264	0.7364	1.9480	0.8397	-1.2162	0.7450	1.9469
21	0.0086	-1.3164	0.9755	-2.2931	1.0124	-0.9353	0.9782	-2.1694
22	0.9409	-1.0022	0.8997	-1.6902	0.9455	-0.3061	0.9032	-1.5811
23	1.0014	-0.3990	0.9859	-0.4744	1.0173	-0.3061	1.0274	-0.1790
24	0.9470	-0.3990	0.9324	-0.4744	0.9620	-0.3061	0.9717	-0.1790
25	0.8612	-0.3990	0.8479	-0.4744	0.8748	-0.3061	0.8836	-0.1790
26	0.7162	-0.3990	0.7051	-0.4744	0.7276	-0.3061	0.7349	-0.1790
27	0.8059	-0.3990	0.7934	-0.4744	0.8186	-0.3061	0.8268	-0.1790
28	0.7334	-0.3990	0.7220	-0.4744	0.7450	-0.3061	0.7525	-0.1790

Table 5: Voltage magnitude and angles for faults on buses 13-16

	Bus 13		Bus 14		Bus 15		Bus 16	
Bus	Voltage Mag	Voltage angle	Voltage Mag	Voltage angle	Voltage Mag	Voltage angle	Voltage Mag	Voltage angle
1	0.9511	-0.8095	1.0328	-0.1529	0.9891	-0.5091	0.9968	-0.4474
2	0.9149	-0.8095	0.9934	-0.1529	0.9514	-0.5091	0.9589	-0.4474
3	0.8724	-0.9695	1.0174	-0.1862	0.9397	-0.6094	0.9536	-0.5365
4	0.8807	-0.9824	1.0205	-0.1875	0.9456	-0.6163	0.9590	-0.5422
5	0.4847	-1.7359	0.9143	-0.2964	0.6842	-0.9799	0.7252	-0.8554
6	0.4520	-2.1921	0.8788	-0.3371	0.6503	-1.1713	0.6910	-1.0126
7	0.4500	-2.3400	0.8834	-0.3498	0.6513	-1.2318	0.6926	-1.0621
8	0.4466	-2.4185	0.8812	-0.3564	0.6484	-1.2637	0.6899	-1.0882
9	0.4237	-2.4185	0.8359	-0.3564	0.6151	-1.2637	0.6544	-1.0882
10	0.5783	-2.7429	0.9677	-0.4023	0.7591	-1.4695	0.7963	-1.2625
11	0.5579	-2.7429	0.9336	-0.4023	07324	-1.4695	0.7682	-1.2625
12	0.4898	-3.6126	0.9721	-0.4610	0.7137	-1.7670	07597	-1.5005
13	0.0000	0.0000	0.8619	-0.2891	0.4003	-0.7600	0.4825	-0.6976
14	0.0000	0.0000	0	0.0000	0.4164	-0.7600	0.5019	-0.6976
15	0.3333	-4.9761	0.9249	-0.4977	0.0000	0.0000	0.5291	-2.0757
16	0.3475	-4.7073	0.9274	-0.4885	0.4648	-2.5143	0.0000	0.0000
17	0.3394	-4.8389	0.9235	-0.4931	0.2318	-2.5143	0.2638	-2.0757
18	0.2922	19.5658	0.8659	0.9325	0.5521	5.8948	0.6075	4.5903
19	0.3096	19.5658	0.9174	0.9325	0.5850	5.8948	0.6436	4.5903
20	0.2801	19.5658	0.83	0.9325	0.5293	-4.8042	0.5823	4.5903
21	0.8147	-8.5167	1.0081	-1.2542	0.9031	-3.5803	0.9217	-4.1235
22	0.6948	-6.5590	0.9406	-0.9202	0.8083	-0.3573	0.8318	-3.0593
23	1.9828	-0.5623	1.0383	-0.1083	0.0086	-0.3573	1.0139	-0.3146
24	0.9294	-0.5623	0.9819	-0.1083	0.9538	-0.3573	0.9588	-0.3146
25	0.8452	-0.5623	0.8929	-0.1083	0.8674	-0.3573	0.8719	-0.3146
26	0.7029	-0.5623	0.7426	-0.1083	0.7214	-0.3573	0.7252	-0.3146
27	0.7909	-0.5623	0.8356	-0.1083	0.8117	-0.3573	0.8159	-0.3146
28	0.7198	-0.5623	0.7604	-0.1083	0.7387	-0.3573	0.7425	-0.3146

Fig. 3-6. Each of the graphs in Fig. 3 shows the plot of current magnitude against the appropriate line at the faulted bus. On the above basis, the currents flowing in the lines of the test system as well as the corresponding

Table 6: Voltage magnitude and angles for faults on buses 17-20

	Bus 17		Bus 18		Bus 19		Bus 20	
Bus	Voltage Mag	Voltage angle	Voltage Mag	Voltage angle	Voltage Mag	Voltage angle	Voltage Mag	Voltage angle
1	1.0097	-0.3842	1.0257	-0.2509	1.0315	-0.3511	1.0359	-0.0968
2	0.9712	-0.3842	0.9866	-0.2509	0.9922	-0.3511	0.9964	-0.0968
3	0.9763	-0.4871	1.0048	-0.3267	1.0147	-0.5347	1.0229	-0.1013
4	0.9809	-0.4881	1.0083	-0.3260	1.0180	-0.5233	1.0258	-0.1043
5	0.7924	-0.9188	0.8767	-0.6402	0.9056	-1.4206	0.9307	-0.0749
6	0.7578	-1.0384	0.8415	-0.7083	0.8703	-1.5034	0.8952	-0.1021
7	0.7605	-1.0759	0.8455	-0.7295	0.8748	-1.5294	0.9000	-0.1105
8	0.7579	-1.0955	0.8432	-0.7406	0.8725	-1.5427	0.8978	-0.1149
9	0.7190	-1.0955	0.7999	-0.7406	0.8277	-1.5427	0.8517	-0.1149
10	0.8574	-1.1630	0.9338	-0.7630	0.9603	-1.3807	0.9826	-0.1838
11	0.7271	-1.1630	0.9008	-0.7630	0.9265	-1.3807	0.9480	-0.1838
12	0.8353	-1.3828	0.9299	-0.8970	0.9628	-1.6669	0.9905	-0.1967
13	0.6172	-1.2481	0.7862	-0.9019	0.8438	-2.6736	0.8951	0.1126
14	0.6420	-1.2481	0.8179	-0.9019	0.8777	-2.6736	0.9311	0.1126
15	0.5025	-2.2226	0.8732	-1.0270	0.9134	-2.0478	0.9475	-0.1762
16	0.4591	-2.4621	0.8767	-1.0055	0.9161	-2.0032	0.9496	-0.1739
17	0.0000	0.0000	0.8724	-1.0163	0.9121	-2.0225	0.9459	-0.1751
18	0.6977	2.5310	0.0000	0.0000	0.2411	-28.1900	0.4217	4.6461
19	0.7393	2.5310	0.0000	0.0000	0.0000	0.0000	0.4468	4.6461
20	0.6689	2.5310	1.11E-16	180.0000	0.2311	-28.1900	0.0000	0.0000
21	0.9531	-3.1572	0.7694	-15.7950	0.8546	-13.5420	0.8714	-4.2478
22	0.8709	-2.3924	0.6184	-15.3960	0.7216	-14.0000	0.7613	-6.0831
23	1.0226	-0.2696	1.0335	-0.1763	1.0374	-0.2427	1.0404	-0.0695
24	0.9671	-0.2696	0.9774	-0.1763	0.9811	-0.2427	0.9839	-0.0695
25	0.8795	-0.2696	0.8888	-0.1763	0.8922	-0.2427	0.8947	-0.0695
26	0.7314	-0.2696	0.7392	-0.1763	0.7420	-0.2427	0.7441	-0.0695
27	0.8230	-0.2696	0.8317	-0.1763	0.8349	-0.2427	0.8373	-0.0695
28	0.7489	-0.2696	0.7569	-0.1763	0.7598	-0.2427	0.7620	-0.0695

Table 7: Voltage magnitude and angles for faults on buses 21-24

	Bus 21		Bus 22		Bus 23		Bus 24	
Bus	Voltage Mag	Voltage angle	Voltage Mag	Voltage angle	Voltage Mag	Voltage angle	Voltage Mag	Voltage angle
1	1.0409	-0.3646	1.0398	-0.3796	0.9114	-0.7600	0.9915	-0.4957
2	1.0013	-0.3646	1.0002	-0.3796	0.8766	-0.7600	0.9537	-0.4957
3	1.0314	-0.6032	1.0294	-0.6246	0.8024	-0.6285	0.9441	-0.5974
4	1.0341	-0.5848	1.0321	-0.6059	0.8132	-0.6832	0.9498	-0.6035
5	0.9546	-1.7574	0.9487	-1.8135	0.9022	-0.3179	0.9615	-0.2789
6	0.9191	-1.8308	0.9132	-1.8912	0.8969	-0.2738	0.9385	-0.2205
7	0.9244	-1.8539	0.9184	-1.1596	0.9110	-0.2624	0.9480	-0.2031
8	0.9223	-1.8656	0.9163	-1.9279	0.9134	-0.2539	0.9478	-0.1934
9	0.8749	-1.8656	0.8692	-1.9279	0.8665	-0.2539	0.8991	-0.1934
10	1.0051	-1.5959	0.9997	-1.6527	1.0106	-0.2339	1.0334	-0.1514
11	0.9696	-1.5959	0.9645	-1.6527	0.9750	-0.2339	0.9970	-0.1514
12	1.0180	-1.9326	1.0116	-2.0022	1.0561	-0.1164	1.0665	-0.0728
13	0.9422	-3.3956	0.9303	-3.5106	1.0155	-0.1307	1.0320	-0.0939
14	0.9801	-3.3956	0.9677	-3.5106	1.0563	-0.1307	1.0735	-0.0939
15	0.9812	-2.4089	0.9731	-2.5106	1.0304	-0.1325	1.0418	-0.0823
16	0.9826	-2.3586	0.9746	-2.4957	1.0308	-0.1301	1.0419	-0.0808
17	0.9791	-2.3837	0.9711	-2.4432	1.0277	-0.1313	1.0389	-0.0816
18	0.6156	-18.4609	0.5729	-2.4694	0.9712	0.0641	0.9826	-0.0018
19	0.6523	-18.4609	0.6070	-20.1342	1.0290	0.0641	1.0411	-0.0018
20	0.5901	-18.4609	0.5492	-20.1342	0.9310	0.0641	0.9419	-0.0018
21	0.0000	0.0000	0.2674	-20.1342	1.0436	-0.2108	1.0474	-0.0978
22	0.0927	-20.7202	0.0000	-40.5290	0.9849	-0.1652	0.9896	-0.0814
23	1.0439	-0.2499	1.0431	0.0000	0.0000	0.0000	0.6053	-2.4731
24	0.9872	-0.2499	0.9865	-0.2602	0.0000	0.0000	0.0000	0.0000
25	0.8977	-0.2499	0.8971	-0.2602	0.0000	0.0000	0.5205	-2.4731
26	0.7466	-0.2499	0.7461	-0.2602	0.0000	0.0000	0.4329	-2.4731
27	0.8401	-0.2499	0.8394	-0.2602	0.0000	0.0000	0.4871	-2.4731
28	0.7645	-0.2499	0.7639	-0.2602	0.0000	0.0000	0.4433	-2.4731

ratings of the circuit breakers to be installed were determined and recommended for selection. Table 9 shows the calculated circuit breaker MVA rating for each line in the transmission network. When short-circuit occurs, the voltage magnitude and angle at the faulted point reduced to almost zero as highlighted in Table 2-8.

Table 8: Voltage magnitude and angles for faults on buses 25-28

	Bus 25		Bus 26		Bus 27		Bus 28	
Bus	Voltage Mag	Voltage angle	Voltage Mag	Voltage angle	Voltage Mag	Voltage angle	Voltage Mag	Voltage angle
1	0.9805	-0.5355	1.0179	-0.2975	1.0160	-0.3132	1.0298	-0.1909
2	0.9431	-0.5355	0.9792	-0.2975	0.9773	-0.3132	0.9905	-0.1909
3	0.9246	-0.6124	0.9910	-0.3716	0.9876	-0.3904	1.0120	-0.2391
4	0.9310	-0.6239	0.9951	-0.3731	0.9918	-0.3921	1.0153	-0.2398
5	0.9534	-0.2886	0.9812	-0.1751	0.9797	-0.1838	0.9899	-0.1135
6	0.9328	-0.2308	0.9523	-0.1374	0.9513	-0.1442	0.9585	-0.0891
7	0.9429	-0.2139	0.9602	-0.1260	0.9593	-0.1324	0.9656	-0.0817
8	0.9431	-0.2041	0.9592	-0.1197	0.9584	-0.1258	0.9643	-0.0776
9	0.8946	-0.2041	0.9099	-0.1197	0.9091	-0.1258	0.9147	-0.0776
10	1.0302	-0.1642	1.0409	-0.0915	1.0404	-0.0963	1.0443	-0.0591
11	0.9939	-0.1642	1.0042	-0.0915	1.0037	-0.0963	1.0075	-0.0591
12	1.0650	-0.0795	1.0699	-0.0438	1.0696	-0.0461	1.0714	-0.0283
13	1.0297	-0.1001	1.0374	-0.0579	1.0370	-0.0608	1.0398	-0.0375
14	1.0711	-0.1001	1.0791	-0.0579	1.0787	-0.0608	1.0817	-0.0375
15	1.0402	-0.0900	1.0455	-0.0495	1.0452	-0.0521	1.0472	-0.3190
16	1.0404	-0.0883	1.0456	-0.0486	1.0453	-0.0511	1.0472	-0.0313
17	1.0373	-0.0891	1.0425	-0.0490	1.0423	-0.0516	1.0442	-0.0316
18	0.9810	0.0063	0.9864	-0.0058	0.9861	-0.0058	0.9881	-0.0044
19	1.0394	0.0063	1.0451	-0.0058	1.0448	-0.0058	1.0469	-0.0044
20	0.9404	0.0063	0.9456	-0.0058	0.9453	-0.0058	0.9472	-0.0044
21	1.0469	-0.1136	1.0486	-0.0551	1.0485	-0.0582	1.0491	-0.0350
22	0.9890	-0.0933	0.9912	-0.0466	0.9911	-0.0492	0.9918	-0.0297
23	0.5220	-2.5586	0.8059	-1.3309	0.7914	-1.4108	0.8958	-0.8008
24	0.4936	-2.5586	0.7621	-1.3309	0.7484	-1.4108	0.8471	-0.8008
25	0.0000	0.0000	0.4851	-1.6003	0.4603	-1.7133	0.6390	-0.8739
26	7.31E-18	-90.0000	0.0000	0.0000	0.3828	-1.7133	0.5314	-0.8739
27	7.31E-18	-90.0000	0.4540	-1.6003	0.0000	0.0000	0.3410	-0.4929
28	1.11E-16	-3.7695	0.4131	-1.6003	1.12E-16	-172.6500	0.0000	0.0000

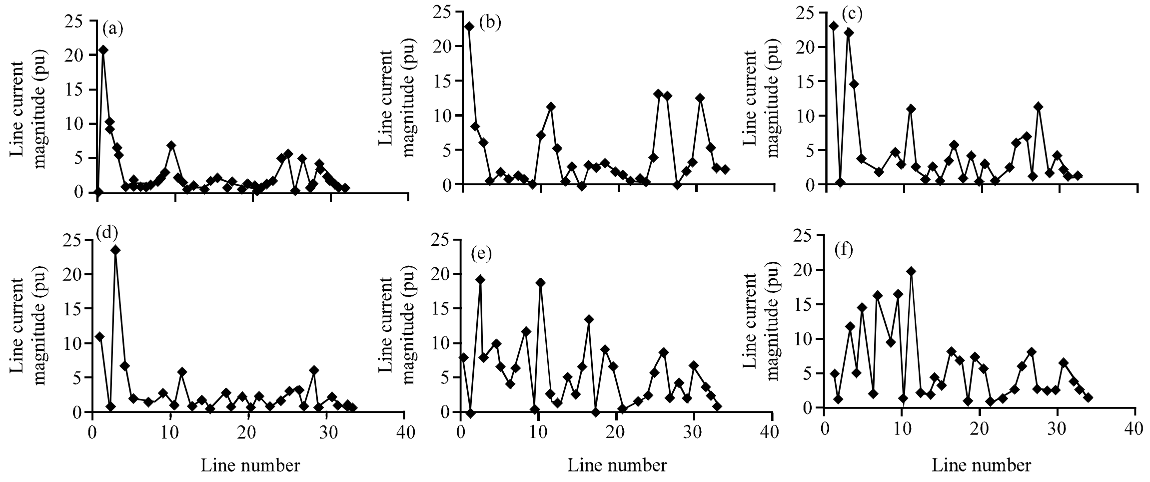

Fig. 3: Line current magnitude (pu) for faults on buses 1-6: a) Line current magnitude with a fault at bus 1: Kainji; b) Line current magnitude with a fault at bus 2: B/Kebbi; c) Line current magnitude with a fault at bus 3: Jeeba TS; d) Line current magnitude with a fault at bus 4: Jeeba GS; e) Line current magnitude with a fault at bus 5: Osogbo and f) Line current magnitude with a fault at bus 6: Ayede

It is observed that in most of the buses,the voltages dropped below the acceptable limit of -10% except at buses 24-28 where the voltage magnitude were lowered to zero when Shiroro bus was faulted. These are voltage violated buses as revealed in Table 1 due to long power lines. Similar case occurred at bus 14 when bus 13 was faulted.

It is observed from Table 9 that currents of abnormally high magnitudes flow through the power lines of the test system to the point of fault and recorded the highest value of 6.4376 kA (36.796 pu) through the line 4-3 when Jebba GS is short-circuited. The excessive high current of line 4-3 occurs because the fault occurring is very close to a solidly grounded generator terminal and

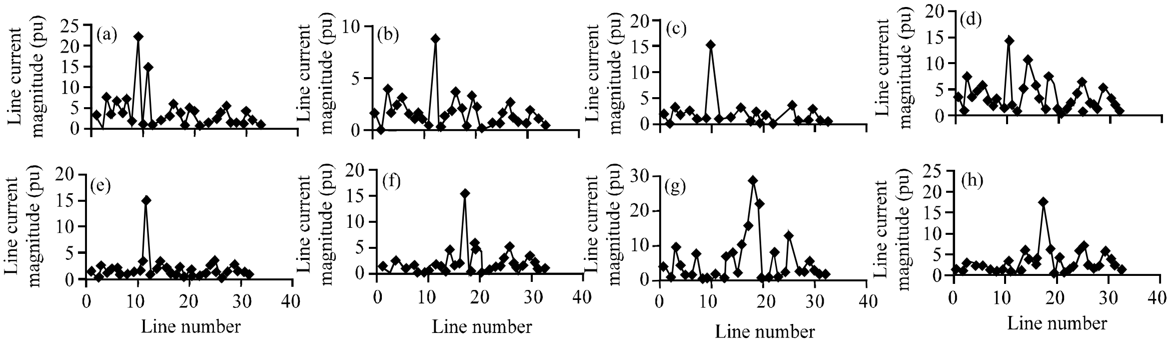

Fig. 4: Line current magnitude (pu) for faults on buses 7-14: a) Line current magnitude with a fault at bus 7: Papalanto; b) Line current magnitude with a fault at bus 8: Ikeja West; c) Line current magnitude with a fault at bus 9: Akangba TS; d) Line current magnitude with a fault at bus 10: Egbin; e) Line current magnitude with a fault at bus 11: Aja; f) Line current magnitude with a fault at bus 12: Omotosho; g) Line current magnitude with a fault at bus 13: Benin and h) Line current magnitude with a fault at bus 14: Ajaokuta

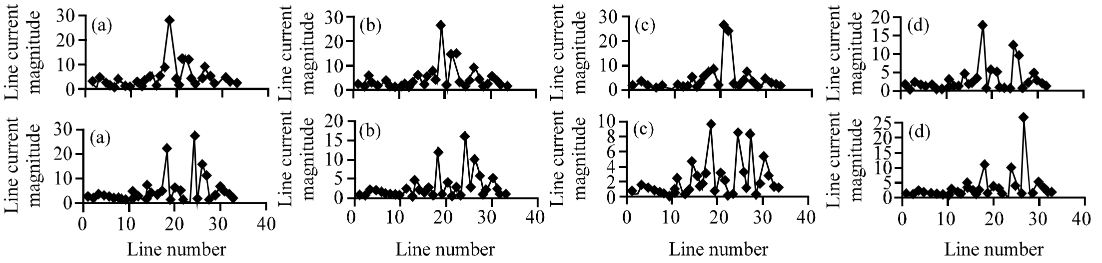

Fig. 5: Line current magnitude (pu) for faults on buses 15-22: a) Line current magnitude with a fault at bus 15: Sapele; b) Line current magnitude with a fault at bus 16: Delta; c) Line current magnitude with a fault at bus 17: Aladaja; d) Line current magnitude with a fault at bus 18: Onitsha; e) Line current magnitude with a fault at bus 19: Aja; f) Line current magnitude with a fault at bus 20: New Haven; g) Line current magnitude with a fault at bus 21: Afam; h) Line current magnitude with a fault at bus 22: Alaoji

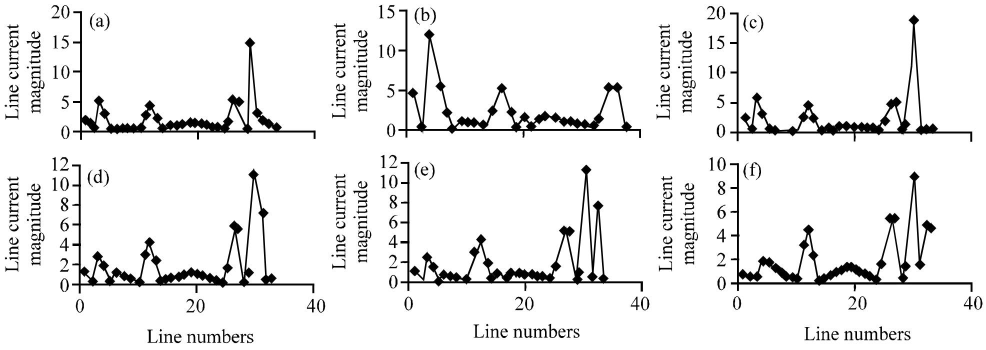

Fig. 6: Line current magnitude (pu) for faults on buses 23-28: a) Line current magnitude with a fault at bus 24: Katampe; b) Line current magnitude with a fault at bus 23: Shiroro; c) Line current magnitude with a fault at bus 25: Kaduna; d) Line current magnitude with a fault at bus 26: Kano; e) Line current magnitude with a fault at bus 27: Jao and f) Line current magnitude with a fault at bus 28: Gombe

this can even be higher for a single line-to-ground fault. As seen from Table 9, other lines with high current magnitudes are 10-11 (5.162 kA), 15-17 (4.5937 kA), 8-7 (4.543 kA) and 8-9 (4.355 kA) when Aja, Aladja, Papalanto and Akangba are short circuited, respectively.

CONCLUSION

In this study, the system performance of the test system was analyzedat steady state using Newton-Raphson in Power World Simulator and the values of current flowing in the system when fault occurs were calculated for the fault analysis on the system. It was revealed that the voltage magnitudes at some buses fell outside the acceptable voltage levelrange due to long transmission lines.The fault analysis was carried out afterwards to determine the current and voltage when fault occurs. The results of three-phase fault showed extremely large current flows.These are used in the calculation of appropriate rating of circuit breaker required to protect the 330 kV Nigeria transmission lines from symmetrical fault. The study showed that all the voltage profile violated-buses recorded a lower voltage of zero during fault analysis when bus 23 (Shiroro) was faulted.

The fault analysis was carried outat every single bus for all the 28 buses in the test system in order to improve on the poor system protection for high voltage stability. Finally, more substations and additional lines should be introduced into the network to improve the voltage profile of the network, especially all the buses that were discovered in this work.

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