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Investigating the Effect of Asymmetrical Faults at Some Selected Buses on the Performance of the Nigerian 330-kV Transmission System

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Abstract
This study presents the investigation of the effects of the various types of asymmetrical faults on the Nigerian grid. Simulation of the different types of short-circuit faults was carried out on the network using Power World Simulator (PWS) to examine their effects on the bus voltages and currents. Load-flow analysis was also carried out on the existing 28-bus Nigerian transmission grid using Newton-Raphson algorithm in the run mode of the Power World Simulator. The study revealed voltage violations at several buses and voltage dip at some buses due to asymmetrical faults. This has an adverse effect on the power system stability. Prolonged faults could eventually result in power outages. Recommendations to minimise the effects of these asymmetrical faults are proffered to ensure good power system stability and prevent outages in the network.

Keywords: Asymmetrical Faults, Steady-State, 330-kV transmission grid, Power World Simulator, Newton-Raphson algorithm, Voltage dip

Introduction

The Nigerian transmission network just like most transmission networks in the world is faced with problems as power outages. A power outage also known as blackout is the loss of electrical power in a place and it may be a short-term or long-term loss. The major cause of power outages in an electrical network is faults. The level of power availability in developing countries like Nigeria is really low due to erratic and epileptic state of power supply. Majority of the outages recorded by Nigerian Electricity Supply Industry (NESI) are the underlying problem in the transmission network. For instance, 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 76.6% were caused by transmission faults [1]The purpose of an electrical power system is to generate and supply electrical energy to consumers with reliability and economy. The current trends of erratic power supply and system collapse due to outage in Nigeria have made this study a paramount importance to the nation's power industry [2].

The normal operation of power systems is under balanced conditions but an abnormal condition could cause the system to become unbalanced. The main objective of all power systems is to maintain continuous supply of power under balanced and unbalanced conditions. But, an unbalanced condition could lead to interrupted power supply. A fault can be defined as any failure in the power system which interferes with its normal mode of operation. Fault is also any hindrance to the normal or conventional flow of current and it can occur at any point in the power system.

Short circuits, which are also referred to as faults, are of the greatest concern because they could lead to damage of equipment or system elements and other operating problems including voltage drops, decrease in frequency, loss of synchronism, power system instability and complete collapse of the system [2]. The consequences of faults may also include loss of supply to loads, reoccurring events leading to blackouts. There is therefore the need to examine the fault or short circuits on a power system for various levels of voltage magnitude and angle circumstances against the effective power transmission in Nigeria 330-kV network.

The main aim of this research work is to investigate the effect of asymmetrical faults at some selected buses in Nigeria 330-kV power line. The selection of these specific buses is partly based on the voltage violations as observed from the reviewed power-flow analysis and also on the strategic location of some of the buses in the grid.

Materials and Procedure

The materials used to perform this research work and the methodologies employed in this study include the following:

- Review of the existing Nigeria 330-kV transmission network at steady-state.
- Data collected from PHCN such as Line data, bus data, generator data, positive negative and zero sequence bus impedance Matrix.
- Load flow analysis using Power World Simulator software to evaluate bus voltages, branch current, real and reactive power flow under steady-state balanced condition.
- Asymmetrical fault analysis at some selected buses on the test system using Power World Simulator.
- Analysing the effects of the asymmetrical fault on the test system.

Test System For Fault Analysis

The test system for this research work is the Nigeria 330-kV transmission system. The system consists of eight generating stations across the country and twenty-eight buses. The transmission network is made up of 5,000 km of 330-kV lines, 6,000 km of 132-kV lines, 23 of 330-kV/132-kV substations. The transmission system is centrally controlled at Oshogbo in Osun State where the National Control Centre (NCC) is located. The single-line diagram of the existing 28-bus, 330-kV Nigerian transmission network used for this analysis is shown in Figure 1.Bus identifications are shown in Table 1.

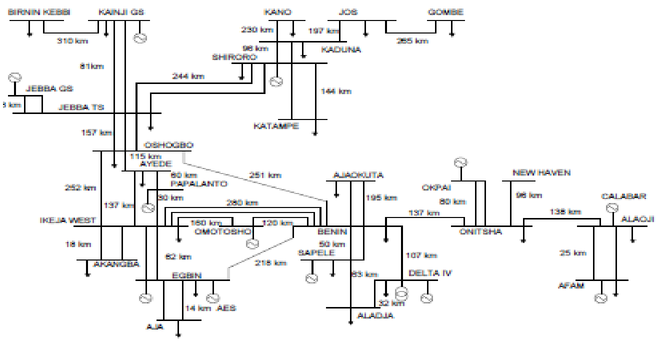

Figure 1: Single Line Diagram of the existing 28 bus 330-kV Nigerian transmission system

Table 1: Bus Identifications of the Nigerian 28 bus system

Bus No	Bus Name	Bus No	Bus Name
1	Birnin-Kebbi	15	Sapele
2	Kainji GS	16	Ajaokuta
3	Jebba TS	17	Delta IV
4	Jebba GS	18	Aladja
5	Osogbo	19	Onitsha
6	Ayede	20	Okpai
7	Papalanto	21	New-Haven
8	Ikeja-West	22	Afam
9	Akangba	23	Alaoji
10	Egbin (slack)	24	Shiroro
11	Aja	25	Kano
12	Katampe	26	Kaduna
13	Omotosho	27	Jos
14	Benin	28	Gombe

Review of Existing Fault Analysis Methods

In this section, a brief review of power system faults and methods of analysing unbalanced faults is undertaken. Power system fault analysis is the analysis of the system after a fault occurs. This analysis is usually carried out in per unit quantities. Thus, the results obtained from the fault analysis of power systems are used to determine the type and size of protective systems to be installed on the power system.
Most fault conditions result in making the power system unbalanced. Symmetrical components and phase-sequence networks are the two best ways to analyse faults in asymmetrical three-phase power systems because in most cases, the portion of the system that is unbalanced can be isolated from the remaining system.

The method of symmetrical components was suggested by C.L. Fortesque in the year 1918 in a paper he wrote titled "Method of Symmetrical Coordinates Applied to the Solution of Polyphase Networks." In the paper, Fortesque described how arbitrary unbalanced three-phase voltages (or currents) could be transformed into three sets of balanced 3-phase components [3]. The conclusion drawn from the paper was that unbalanced problems can be solved by resolving currents and voltages into symmetrical relations. However, the two main effects of asymmetrical fault are voltage asymmetry and current asymmetry.

According to [4], the balanced set of components is described as positive sequence component, negative sequence component and zero sequence component and these are show below

According to [5], the symmetrical components can be used to determine any unbalanced current or voltage (I_a, I_b, $I_c$or V_a, V_b, V_c) as follows:

$Ia = I_1 + I_2 + I_0$ $V_a = V_1 + V_2 + V_0$

$I_b = a^2I_1 + aI_2 + I_0$ $V_b= a^2V_1 + aV_2 + V_0$

$I_c = aI_1 + a^2I_2 + I_0$ $V_c= aV_1 + a^2V_2 + V_0$

The sequence currents or voltages from a three phase unbalanced set can then be calculated using the following equations:

Positive Sequence Component:

$I_1 = ⅓ (I_a + aI_b + a^2I_c)$

$V_1 = ⅓ (V_a+ aV_b+ a^2V_c)$

Negative Sequence Component:

$I_2 = ⅓ (I_a+ a^2I_b + aI_c)$

$V_2 = ⅓ (V_a + a^2V_b + aV_c)$

Zero Sequence Component:

$I_0 = ⅓ (I_a + I_b + I_c)$

$V_0 = ⅓ (V_a + V_b + V_c)$

When the fault impedance (Z_f) is zero, a direct short circuit occurs and this is called bolted fault because maximum fault current flows here. In practice, fault impedance is not frequently zero because most faults are the direct result of insulator flashovers. During insulator flashovers, the impedance between the line and ground depends on similar factors like resistance of the arc, resistance of the tower and resistance of the tower footing. The majority of the resistance between line and ground is contributed by the tower footing resistance [6].

Brief Review of Voltage-Violated Buses

Power-flow analysis is simply the analysis that concerns the performance of the network in its normal operating conditions. The main reason for performing power-flow analysis is to investigate the magnitude and phase angle of the voltage at each bus and the real and reactive power flows in the system components. Power-flow analysis is the analysis performed when the power system is in a steady state. A steady state is the state of the system before a fault occurs. The power-flow analysis is used to know the initial values of the buses and system components before any fault occurs. The values here are the reference values which are compared to the values obtained from the fault analysis. The summary of load-flow results of voltage-violated buses as reported by some authors in the literature areas follows:

According to [7], after the load-flow analysis, some buses violated the voltage limit (-5%) and they include Birnin-Kebbi (0.86508pu), Katampe (0.9191pu), Kaduna (0.77669pu), Jos (0.47355pu), Kano (0.515pu) and Gombe (0.25006pu).

Also according to [8], the following buses violated the voltage limit after the load-flow analysis was performed; Ayede (0.972), New Haven (0.946), Onitsha (0.967), Gombe (0.897) and Kano (0.963).

The load-flow analysis performed in [9] revealed that the following buses violated the voltage limit; Jos (0.76pu), Gombe (0.65964), Kano (0.74893), Kaduna (0.90349).

Load-Flow Simulation

The load-flow study on the existing Nigerian330-kV transmission grid system was performed to ascertain the current operation of the system and also to determine if the bus voltages are within the specified limits (±5%). The single-line diagram of the Nigeria 330-kV transmission system was redrawn in the edit mode of the power world simulator. The main simulation was done in the run mode and the run mode enabled the simulation using Newton-Raphson iterative method in order to obtain bus voltages, phase angles, real and reactive power flows, and line losses. All these data were obtained after inputting line data, load data and generator data obtained from PHCN into the dialogue box of the power world simulator in edit mode. Figure 2 below shows the existing transmission system simulated in the run mode of the power world simulator.

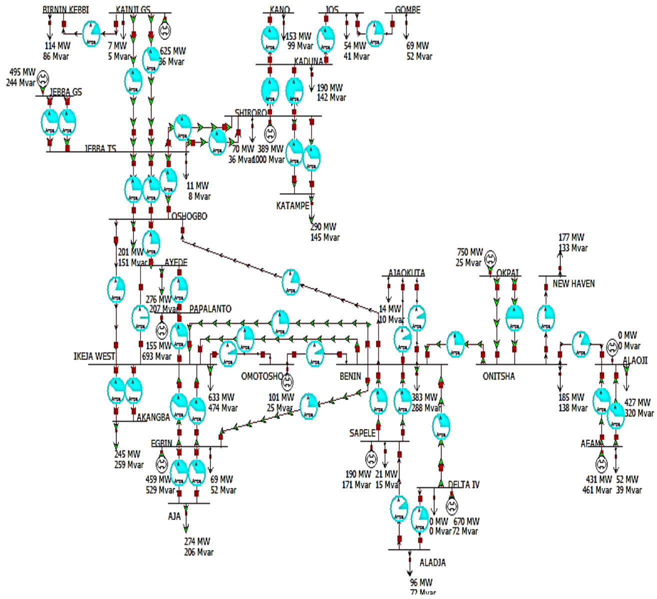

Figure 2: Existing Nigeria 330-kV Transmission System (Simulated in the Run mode)

The table 2 below shows the bus records under normal operating conditions. This result was obtained from the simulation of the existing Nigeria 330-kV transmission system.

Table 2: Bus records under normal operating conditions

Number	Name	Nom (kV)	Volt (pu)	Volt (kV)	Angle (Deg)
1	BIRNIN KEBBI	330	0.91829	303.036	14.89
2	KAINJI GS	330	1	330	21.22
3	JEBBA GS	330	1	330	14.62
4	JEBBA TS	330	0.99364	327.9	14.09
5	OSHOGBO	330	0.95237	314.282	1.44
6	AYEDE	330	0.95812	316.179	-3.34
7	PAPALANTO	330	1	330	-2.98
8	IKEJA WEST	330	0.955	315.151	-3.21
9	AKANGBA	330	0.90079	297.262	-5.65
10	EGBIN(SLACK)	330	1	330	0
11	AJA	330	0.95785	316.092	-2.57
12	KATAMPE	330	0.81797	269.93	-18.06
13	OMOTOSHO	330	1	330	9.93
14	BENIN	330	0.97733	322.52	8.88
15	SAPELE	330	1	330	10.9
16	AJAOKUTA	330	0.99117	327.085	8.31
17	DELTA IV	330	1	330	14.09
18	ALADJA	330	0.99379	327.952	12
19	ONITSHA	330	0.93172	307.469	15.74
20	OKPAI	330	1	330	18.8
21	NEW HAVEN	330	0.88483	291.993	12.4
22	ALAOJI	330	0.93614	308.927	10.01
23	AFAM	330	1	330	9.28
24	SHIRORO	330	0.90822	299.712	-9.56
25	KANO	330	0.43953	145.045	-41.84
26	KADUNA	330	0.64409	212.551	-22.19
27	JOS	330	0.47947	158.225	-35.21
28	GOMBE	330	0.36216	119.512	-49.13

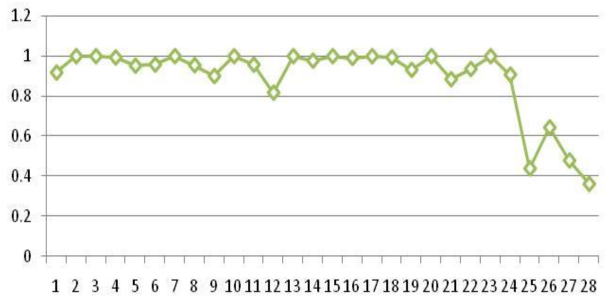

Figure 2: Voltage profile under normal conditions

The load-flow analysis also provided the buses that violated the voltage limit. These buses are presented in the figure 3.

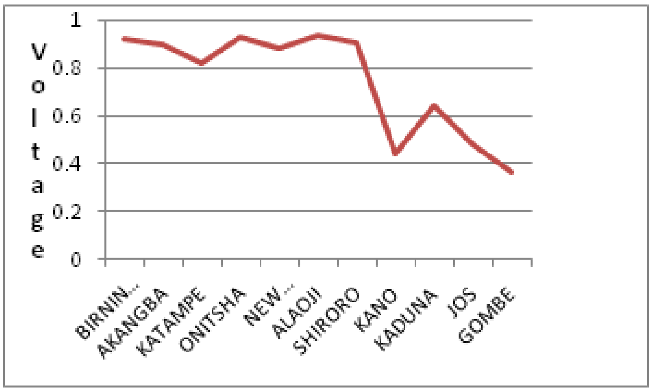

Figure 3: Violated buses and their voltages in pu

Selection of Buses

Previous works reviewed in section 3.2 showed the list of buses that frequently violated the voltage limit. Thus, a load-flow analysis was first performed in this research work in order to ascertain that these buses actually violated the voltage limit. The load-flow analysis carried out in this research work validated the selection of the buses for fault simulation because all of them violated the voltage limit. The buses that have been observed from past works to frequently violate the voltage limit include Kano, Kaduna, Gombe, Jos, BirninKebbi, New Haven, Katampe, Onitsha and Ayede. All these buses have been accounted for from the load-flow analysis performed in this research work and in addition to these buses, the load-flow solution revealed two more buses (Alaoji and Akangba) that violated the voltage limit. In addition to this, there were three other specific buses chosen for 'effect of fault investigation' based on the strategic locations, like Oshogbo which is the major bus linking the southern and northern parts of the grid and is also the location of the National Control Centre (NCC). Benin bus was chosen because it links the eastern, western and northern parts of the grid whereas, Ikeja West bus was chosen because it is attached to the highest generating stations located at Egbin and AES. Based on the above, the total buses chosen for simulation are as presented in table 3.

Table 3: Selected Buses for Fault Simulation

S/N	Bus Number	Bus Name
1	1	BirninKebbi
2	5	Oshogbo
3	8	Ikeja West
4	9	Akangba
5	12	Katampe
6	14	Benin
7	19	Onitsha
8	21	New Haven
9	22	Alaoji
10	24	Shiroro
11	25	Kano
12	26	Kaduna
13	27	Jos
14	28	Gombe

Results and Discussions

Simulation of the different types of asymmetrical faults discussed in section 3.4 is carried out at some selected buses as presented in table 3 using the run mode of power world simulator. The three types of asymmetrical faults are simulated using this simulator and assuming fault impedance $Z_f = 0$. The fault simulation is performed on the aforementioned test system and the effects of the asymmetrical faults on voltage magnitudes and line currents are examined. The asymmetrical faults are simulated at some specific buses as presented in table 3 (14 buses were selected).

Single Line-To-Groud Fault Simulation

The bus voltages (both in magnitude and phase) after the simulation of single line-to-ground fault are shown in tables 4.1-4.4 as well as figure 5 for all the 14 buses selected. The result showed that the voltage magnitude of the faulted buses is always zero for single line-to-ground faults. The result of simulation showed that buses 5, 8, 9, and 19 when subjected to SLG have similar voltage profiles; the same for buses 27 and 28. Detailed results of low and high voltages values recorded when each of the buses is subjected to single line-to-ground fault are presented in table 5. However, the highest voltage of 3.26 per-unit was recorded at bus 28 (Gombe) when bus 5 (Oshogbo) was subjected to the fault.

Table 4.1: Voltage magnitudes and angles for SLG faults on buses 1, 5, 8 and 9

Bus No.	Bus Name	Bus 1		Bus 5		Bus 8		Bus 9	
		Phase Volt A	Phase Ang A	Phase Volt A	Phase Ang A	Phase Volt A	Phase Ang A	Phase Volt A	Phase Ang A
1	BirninKebbi	0	0	1.2167	41.12	1.28219	32.74	1.20087	25.82
2	Kainji GS	0.79535	28.88	1.25058	43.36	1.33224	36.08	1.26039	30.09
3	Jebba GS	0.96125	20.89	1.19666	38.49	1.29755	31.4	1.2394	25
4	Jebba TS	0.9542	20.41	1.18947	38.27	1.29092	31.12	1.23299	24.65
5	Oshogbo	0.99526	9.01	0	0	0.37789	32.82	0.59931	22.13
6	Ayede	1.01238	4.71	0.09094	3.2	0.11333	22.39	0.42018	16.26
7	Papalanto	1.05712	4.65	0.16311	7.38	0.08971	9.83	0.41666	14.98
8	Ikeja West	1.01524	4.86	0.12192	13.39	0	0	0.34237	17.42
9	Akangba	0.95981	3.09	0.07853	3.64	0.04805	-148.4	0	0
10	Egbin	1.06873	7.36	0.22574	24.69	0.1389	32.85	0.45171	20.86
11	Aja	1.02443	5.33	0.18478	19.88	0.09434	26.27	0.40595	17.53
12	Katampe	1.05018	-0.5	2.38795	26.69	2.17754	15.57	1.78812	4.96
13	Omotosho	1.08553	16.14	0.35983	48	0.38175	49.25	0.61388	33.83
14	Benin	1.06656	15.48	0.32215	51.73	0.3521	52.07	0.58376	34.24
15	Sapele	1.09048	17.08	0.37133	51.21	0.40065	51.43	0.62579	35.42
16	Ajaokuta	1.08639	15.11	0.31512	54.13	0.34395	54.44	0.58118	34.74
17	Delta IV	1.09585	19.97	0.40931	57.01	0.43868	56.81	0.65029	39.82
18	Aladja	1.08728	18.13	0.38147	54.19	0.40998	54.17	0.62896	37.3
19	Onitsha	1.03025	21.1	0.47234	54.05	0.48285	53.54	0.65632	39.5
20	Okpai	1.09956	23.61	0.55241	52.81	0.56293	52.34	0.73591	40.5
21	New Haven	0.9821	18.36	0.41376	52.28	0.41983	51.71	0.59599	36.72
22	Alaoji	1.00148	15.56	0.47142	24.23	0.47047	23.98	0.64286	22.02
23	Afam	1.06105	14.55	0.53505	20.01	0.53439	19.73	0.70471	19.24
24	Shiroro	1.15133	4.1	2.45853	27.37	2.26056	17.18	1.87647	7.69
25	Kano	0.75735	0.37	2.71248	30.49	2.31015	17.97	1.73148	5.37
26	Kaduna	0.97146	2.23	2.73718	28.92	2.40598	17.35	1.88385	6.16
27	Jos	0.88757	3.24	3.13973	30.14	2.67351	18.04	2.00247	6.08
28	Gombe	0.78902	4.95	3.25942	31.14	2.72382	18.83	1.98421	6.5

Table 4.2: Voltage magnitudes and angles for SLG faults on buses 12, 14, 19 and 21

Bus No.	Bus Name	Bus 12		Bus 14		Bus 19		Bus 21	
		Phase Volt A	Phase Ang A	Phase Volt A	Phase Ang A	Phase Volt A	Phase Ang A	Phase Volt A	Phase Ang A
1	BirninKebbi	2.13008	35.53	1.20078	31.79	1.09569	25.89	1.05265	21.72
2	Kainji GS	2.10807	37.6	1.26204	35.22	1.16933	30.22	1.12845	26.69
3	Jebba GS	2.07255	34.67	1.23028	30.23	1.14942	24.7	1.11632	20.91
4	Jebba TS	2.06965	34.5	1.22337	29.93	1.14255	24.33	1.1097	20.5
5	Oshogbo	2.43279	27.28	0.45556	16.35	0.67573	8.77	0.78059	7.55
6	Ayede	2.4798	25.16	0.34647	0.85	0.61527	-0.35	0.73766	0.74
7	Papalanto	2.50443	24.65	0.36492	-1.33	0.64333	-0.86	0.76952	0.6
8	Ikeja West	2.48822	25.06	0.29823	-3.34	0.58538	-1.48	0.71542	0.41
9	Akangba	2.43618	24.83	0.25524	-10.78	0.53556	-5.28	0.66226	-2.6
10	Egbin	2.51673	25.42	0.29982	0.59	0.60598	1.96	0.74479	3.8
11	Aja	2.47304	24.93	0.2664	-7.13	0.56704	-2.02	0.70286	0.6
12	Katampe	0	0	1.88284	17.03	1.42175	9.11	1.24119	0.53
13	Omotosho	2.49121	28.48	0.08493	24.35	0.48643	14.85	0.67047	16.36
14	Benin	2.53378	28.33	0	0	0.42829	13.1	0.6238	15.47
15	Sapele	2.52778	28.87	0.05645	47.94	0.4665	17.02	0.65845	18.07
16	Ajaokuta	2.63551	28.11	0.02767	-164.07	0.41776	12.41	0.62147	15.02
17	Delta IV	2.53756	30.06	0.1008	73.38	0.47585	23.68	0.66724	22.8
18	Aladja	2.53436	29.32	0.06764	66.11	0.46269	19.58	0.65488	19.85
19	Onitsha	2.33841	29.82	0.20101	61.22	0	0	0.33436	31.03
20	Okpai	2.38896	31.31	0.28311	55.61	0.0889	41.27	0.41771	33.93
21	New Haven	2.30188	28.81	0.14117	60.29	0.05475	-119.79	0	0
22	Alaoji	2.04742	31.55	0.30972	1.25	0.29055	-27.34	0.46027	3.69
23	Afam	2.07577	31.09	0.38803	-0.41	0.36773	-22.59	0.53507	2.4

24	Shiroro	1.11749	29.52	1.97923	18.69	1.52982	11.97	1.34596	4.67
25	Kano	1.20107	38.7	1.91602	21.33	1.24609	13.61	0.97243	1.26
26	Kaduna	1.22244	34.65	2.04219	19.92	1.43686	12.63	1.1883	2.84
27	Jos	1.40251	38.2	2.22833	21.59	1.45888	14.82	1.13475	3.47
28	Gombe	1.46028	40.5	2.24778	23.02	1.406	16.89	1.04417	4.69

Table 4.3: Voltage magnitudes and angles for SLG faults on buses 22, 24, 25 and 26

Bus No.	Bus Name	Bus 22		Bus 24		Bus 25		Bus 26	
		Phase Volt A	Phase Ang A	Phase Volt A	Phase Ang A	Phase Volt A	Phase Ang A	Phase Volt A	Phase Ang A
1	BirninKebbi	1.0198	22.88	1.63892	102.2	1.66246	14.44	1.66171	77.82
2	Kainji GS	1.1	27.72	1.56793	97.46	1.68276	18.67	1.6708	75.54
3	Jebba GS	1.08597	21.79	1.45279	96.66	1.68919	14.78	1.57808	73.44
4	Jebba TS	1.0791	21.38	1.45114	97	1.68619	14.45	1.57322	73.58
5	Oshogbo	0.78185	3.93	1.9881	100.21	1.84042	4.92	1.84462	74.92
6	Ayede	0.75183	-3.7	2.03295	100.37	1.86929	2.08	1.844	74.33
7	Papalanto	0.78612	-3.78	2.011	98.79	1.90087	2.09	1.84326	72.71
8	Ikeja West	0.73379	-4.43	2.05419	100.21	1.86818	2.05	1.85476	74.29
9	Akangba	0.68308	-7.7	2.05356	101.95	1.81594	0.96	1.81986	75.79
10	Egbin	0.76387	-1.17	2.05201	98.01	1.8947	3.54	1.88149	72.66
11	Aja	0.72479	-4.56	2.03702	99.45	1.85505	2.26	1.84075	73.64
12	Katampe	1.14548	4.87	0.24238	176.43	1.18963	-0.32	0.44381	68.74
13	Omotosho	0.69177	9.16	2.10612	96.06	1.84709	8.72	1.95475	72.86
14	Benin	0.64892	7.31	2.18448	97.4	1.86154	7.97	2.00014	74.05
15	Sapele	0.67864	10.38	2.16699	96.43	1.86266	9.16	2.0014	73.45
16	Ajaokuta	0.64789	6.49	2.30408	97.91	1.92392	7.45	2.09216	74.57
17	Delta IV	0.67999	15.08	2.21351	96.51	1.85683	10.89	2.04371	74.13
18	Aladja	0.67213	12.04	2.19523	96.69	1.85902	9.72	2.02221	73.92
19	Onitsha	0.38651	7.37	2.06199	94.94	1.70221	11.41	1.90014	73.09
20	Okpai	0.45863	14.35	2.07729	94.09	1.75513	13.87	1.94192	72.76
21	New Haven	0.35268	-1.06	2.03621	96.2	1.66932	9.41	1.85333	73.71
22	Alaoji	0	0	1.53981	97.97	1.5877	12.27	1.48092	73.35
23	Afam	0.08446	-9.41	1.4862	96.1	1.63932	12.19	1.46442	71.21
24	Shiroro	1.25949	8.76	0	0	1.28029	4.21	0.53476	54.73
25	Kano	0.85627	9.84	1.26688	144.63	0	0	0.37739	150.71
26	Kaduna	1.08061	9.15	0.7643	143.68	0.83597	2.09	0	0
27	Jos	1.01183	12.2	1.41398	139.88	0.75357	1.18	0.40439	138.8
28	Gombe	0.9208	15.39	1.78055	138.5	0.66109	1.34	0.65599	137.9

Table 4.4: Voltage magnitudes and angles for SLG faults on buses 27 and 28

Bus No.	Bus Name	Bus 27		Bus 28	
		Phase Volt A	Phase Ang A	Phase Volt A	Phase Ang A
1	BirninKebbi	1.91229	22.3	1.28663	7.12
2	Kainji GS	1.92209	25.46	1.32651	12.93
3	Jebba GS	1.9156	22.07	1.34383	8
4	Jebba TS	1.91279	21.82	1.34019	7.54
5	Oshogbo	2.12473	14.06	1.41154	-4.26
6	Ayede	2.15333	11.67	1.43715	-7.79
7	Papalanto	2.18132	11.43	1.47257	-7.4
8	Ikeja West	2.15401	11.63	1.43416	-7.78
9	Akangba	2.09924	10.98	1.38573	-9.59
10	Egbin	2.18062	12.59	1.46223	-5.38
11	Aja	2.13726	11.7	1.42674	-7.31
12	Katampe	1.24057	9.53	1.06144	-12.95
13	Omotosho	2.14136	16.76	1.41505	1.69
14	Benin	2.16739	16.32	1.41302	0.49
15	Sapele	2.16547	17.19	1.42023	2.21
16	Ajaokuta	2.24666	15.96	1.45157	-0.26
17	Delta IV	2.166	18.66	1.40971	4.47
18	Aladja	2.16581	17.7	1.41265	2.9

19	Onitsha	1.98718	18.87	1.29375	5.6
20	Okpai	2.03953	20.85	1.34936	8.78
21	New Haven	1.95151	17.37	1.2615	2.76
22	Alaoji	1.7966	20.21	1.26853	5.03
23	Afam	1.83918	19.94	1.32924	5.08
24	Shiroro	1.33578	12.61	1.14746	-6.53
25	Kano	0.66418	14.33	0.59716	-24.41
26	Kaduna	0.82754	12.52	0.8037	-13.11
27	Jos	0	0	0.405	-16.18
28	Gombe	0.09241	124.72	0	0

Table 5: Detail analysis of the results obtained for SLG fault

Faulted Bus	Low Voltage Bus	High Voltage Bus	Bus within $\pm 5\%$ *Limit*
1	2, 25, 27, 28 (4 buses)	7, 10, 13, 14, 15, 16, 17, 18, 20, 23, 24 (11 buses)	3, 4, 5, 6, 8, 9, 11, 12, 19, 21, 22, 26 (17 buses)
5	6, 7, 8, 9, 10, 11, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23 (17 buses)	1, 2, 3, 4, 12, 24, 25, 26, 27, 28 (10 buses)	No bus voltage within the voltage limit.
8	5, 6, 7, 9, 10, 11, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23 (17 buses)	(1, 2, 3, 4, 12, 24, 25, 26, 27, 28 (10 buses)	No bus voltage within the voltage limit.
9	5, 6, 7, 9, 10, 11, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23 (17 buses)	(1, 2, 3, 4, 12, 24, 25, 26, 27, 28 (10 buses)	No bus voltage within the voltage limit.
12	No low voltage value recorded at any bus	High voltage values recorded at 27 buses.	Not applicable
14	5, 6, 7, 9, 10, 11, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23 (17 buses)	1, 2, 3, 4, 12, 24, 25, 26, 27, 28 (10 buses)	No bus voltage within the voltage limit.
19	5, 6, 7, 9, 10, 11, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23 (17 buses)	1, 2, 3, 4, 12, 24, 25, 26, 27, 28 (10 buses)	No bus voltage within the voltage limit.
21	5, 6, 7, 9, 10, 11, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23 (17 buses)	1, 2, 3, 4, 12, 24, 26, and 27 (8 buses)	25 and 28 (2 buses)
22	5, 6, 7, 9, 10, 11, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24 (18 buses)	1, 2, 3, 4, 12, 26, and 28 (7 buses)	1 and 27 (2 buses)
24	12 and 26 (2 buses)	All the other 25 buses were high	No bus within the voltage limit
25	26, 27 and 28 (3 buses)	All the other 24 buses were high	No bus within the voltage limit
26	24, 25, 26, 27 and 28	All the other 22 buses were high	All the other 24 buses were high
27	25, 26, and 28	All the other 24 buses were high	All the other 24 buses were high
28	25, 26, and 27	All the other 24 buses were high	All the other 24 buses were high

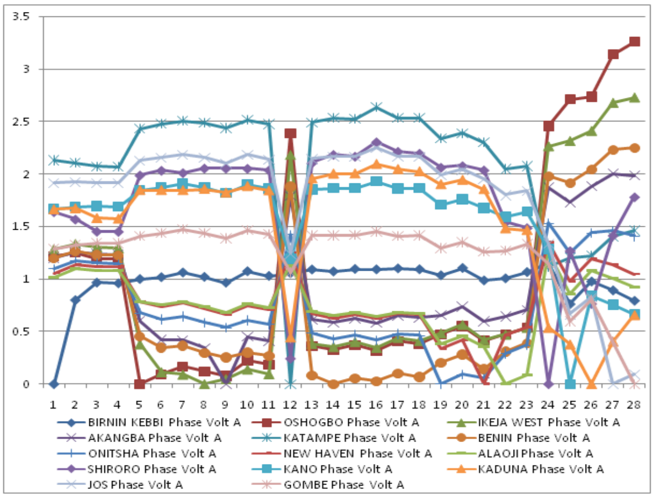

Figure 5: Voltage profiles resulting from simulation of single line-to-ground fault at buses 1, 5, 8 and 9, 12, 14, 19, 21, 22, 24, 25, 26, 27 and 28

LINE-TO-LINE FAULT SIMULATION

The results obtained here showed that when line-to-line fault was simulated at any of the buses, the resulting voltage profiles were the same. The voltage profiles are all similar to the voltage profile under normal operating conditions as shown in figures 2 and 6. When any of the selected buses was subjected to line-to-line fault, low voltage values were recorded at 11 buses (1, 9, 12, 19, 21, 22, 24, 25, 26, 27 and 28) and no high voltage value was recorded at any bus. The result showed that 9 buses (2, 3, 7, 10, 13, 15, 17, 20 and 23) recorded a voltage of 1 per unit while 7 buses (4, 5, 6, 8, 11, 14, 16 and 18) recorded voltages within the voltage limit

Table 4.5: Voltage Magnitudes and Angles for L-L Faults on Buses 1, 5, 8 and 9

Bus No.	Bus Name	Bus 1		Bus 5		Bus 8		Bus 9	
		Phase Volt A	Phase Ang A	Phase Volt A	Phase Ang A	Phase Volt A	Phase Ang A	Phase Volt A	Phase Ang A
1	BirninKebbi	0.91829	14.89	0.91829	14.89	0.91829	14.89	0.91829	14.89
2	Kainji GS	1	21.22	1	21.22	1	21.22	1	21.22
3	Jebba GS	1	14.62	1	14.62	1	14.62	1	14.62
4	Jebba TS	0.99364	14.09	0.99364	14.09	0.99364	14.09	0.99364	14.09
5	Oshogbo	0.95237	1.44	0.95237	1.44	0.95237	1.44	0.95237	1.44
6	Ayede	0.95812	-3.34	0.95812	-3.34	0.95812	-3.34	0.95812	-3.34
7	Papalanto	1	-2.98	1	-2.98	1	-2.98	1	-2.98
8	Ikeja West	0.955	-3.21	0.955	-3.21	0.955	-3.21	0.955	-3.21
9	Akangba	0.90079	-5.65	0.90079	-5.65	0.90079	-5.65	0.90079	-5.65
10	Egbin	1	0	1	0	1	0	1	0
11	Aja	0.95785	-2.57	0.95785	-2.57	0.95785	-2.57	0.95785	-2.57
12	Katampe	0.81797	-18.06	0.81797	-18.06	0.81797	-18.06	0.81797	-18.06
13	Omotosho	1	9.93	1	9.93	1	9.93	1	9.93
14	Benin	0.97733	8.88	0.97733	8.88	0.97733	8.88	0.97733	8.88
15	Sapele	1	10.9	1	10.9	1	10.9	1	10.9
16	Ajaokuta	0.99117	8.31	0.99117	8.31	0.99117	8.31	0.99117	8.31
17	Delta IV	1	14.09	1	14.09	1	14.09	1	14.09
18	Aladja	0.99379	12	0.99379	12	0.99379	12	0.99379	12
19	Onitsha	0.93172	15.74	0.93172	15.74	0.93172	15.74	0.93172	15.74
20	Okpai	1	18.8	1	18.8	1	18.8	1	18.8
21	New Haven	0.88483	12.4	0.88483	12.4	0.88483	12.4	0.88483	12.4
22	Alaoji	0.93614	10.01	0.93614	10.01	0.93614	10.01	0.93614	10.01
23	Afam	1	9.28	1	9.28	1	9.28	1	9.28
24	Shiroro	0.90822	-9.56	0.90822	-9.56	0.90822	-9.56	0.90822	-9.56
25	Kano	0.43953	-41.84	0.43953	-41.84	0.43953	-41.84	0.43953	-41.84
26	Kaduna	0.64409	-22.19	0.64409	-22.19	0.64409	-22.19	0.64409	-22.19
27	Jos	0.47947	-35.21	0.47947	-35.21	0.47947	-35.21	0.47947	-35.21
28	Gombe	0.36216	-49.13	0.36216	-49.13	0.36216	-49.13	0.36216	-49.13

Table 4.6: Voltage Magnitudes and Angles for L-L Faults on Buses 12, 14, 19 and 21

Bus No.	Bus Name	Bus 12		Bus 14		Bus 19		Bus 21	
		Phase Volt A	Phase Ang A	Phase Volt A	Phase Ang A	Phase Volt A	Phase Ang A	Phase Volt A	Phase Ang A
1	BirninKebbi	0.91829	14.89	0.91829	14.89	0.91829	14.89	0.91829	14.89
2	Kainji GS	1	21.22	1	21.22	1	21.22	1	21.22
3	Jebba GS	1	14.62	1	14.62	1	14.62	1	14.62
4	Jebba TS	0.99364	14.09	0.99364	14.09	0.99364	14.09	0.99364	14.09
5	Oshogbo	0.95237	1.44	0.95237	1.44	0.95237	1.44	0.95237	1.44
6	Ayede	0.95812	-3.34	0.95812	-3.34	0.95812	-3.34	0.95812	-3.34
7	Papalanto	1	-2.98	1	-2.98	1	-2.98	1	-2.98
8	Ikeja West	0.955	-3.21	0.955	-3.21	0.955	-3.21	0.955	-3.21
9	Akangba	0.90079	-5.65	0.90079	-5.65	0.90079	-5.65	0.90079	-5.65
10	Egbin	1	0	1	0	1	0	1	0
11	Aja	0.95785	-2.57	0.95785	-2.57	0.95785	-2.57	0.95785	-2.57
12	Katampe	0.81797	-18.06	0.81797	-18.06	0.81797	-18.06	0.81797	-18.06
13	Omotosho	1	9.93	1	9.93	1	9.93	1	9.93
14	Benin	0.97733	8.88	0.97733	8.88	0.97733	8.88	0.97733	8.88
15	Sapele	1	10.9	1	10.9	1	10.9	1	10.9
16	Ajaokuta	0.99117	8.31	0.99117	8.31	0.99117	8.31	0.99117	8.31
17	Delta IV	1	14.09	1	14.09	1	14.09	1	14.09
18	Aladja	0.99379	12	0.99379	12	0.99379	12	0.99379	12
19	Onitsha	0.93172	15.74	0.93172	15.74	0.93172	15.74	0.93172	15.74
20	Okpai	1	18.8	1	18.8	1	18.8	1	18.8
21	New Haven	0.88483	12.4	0.88483	12.4	0.88483	12.4	0.88483	12.4

22	Alaoji	0.93614	10.01	0.93614	10.01	0.93614	10.01	0.93614	10.01
23	Afam	1	9.28	1	9.28	1	9.28	1	9.28
24	Shiroro	0.90822	-9.56	0.90822	-9.56	0.90822	-9.56	0.90822	-9.56
25	Kano	0.43953	-41.84	0.43953	-41.84	0.43953	-41.84	0.43953	-41.84
26	Kaduna	0.64409	-22.19	0.64409	-22.19	0.64409	-22.19	0.64409	-22.19
27	Jos	0.47947	-35.21	0.47947	-35.21	0.47947	-35.21	0.47947	-35.21
28	Gombe	0.36216	-49.13	0.36216	-49.13	0.36216	-49.13	0.36216	-49.13

Table 4.7: Voltage Magnitudes and Angles for L-L Faults on Buses 22, 24, 25 and 26

Bus No.	Bus Name	Bus 22		Bus 24		Bus 25		Bus 26	
		Phase Volt A	Phase Ang A	Phase Volt A	Phase Ang A	Phase Volt A	Phase Ang A	Phase Volt A	Phase Ang A
1	BirninKebbi	0.91829	14.89	0.91829	14.89	0.91829	14.89	0.91829	14.89
2	Kainji GS	1	21.22	1	21.22	1	21.22	1	21.22
3	Jebba GS	1	14.62	1	14.62	1	14.62	1	14.62
4	Jebba TS	0.99364	14.09	0.99364	14.09	0.99364	14.09	0.99364	14.09
5	Oshogbo	0.95237	1.44	0.95237	1.44	0.95237	1.44	0.95237	1.44
6	Ayede	0.95812	-3.34	0.95812	-3.34	0.95812	-3.34	0.95812	-3.34
7	Papalanto	1	-2.98	1	-2.98	1	-2.98	1	-2.98
8	Ikeja West	0.955	-3.21	0.955	-3.21	0.955	-3.21	0.955	-3.21
9	Akangba	0.90079	-5.65	0.90079	-5.65	0.90079	-5.65	0.90079	-5.65
10	Egbin	1	0	1	0	1	0	1	0
11	Aja	0.95785	-2.57	0.95785	-2.57	0.95785	-2.57	0.95785	-2.57
12	Katampe	0.81797	-18.06	0.81797	-18.06	0.81797	-18.06	0.81797	-18.06
13	Omotosho	1	9.93	1	9.93	1	9.93	1	9.93
14	Benin	0.97733	8.88	0.97733	8.88	0.97733	8.88	0.97733	8.88
15	Sapele	1	10.9	1	10.9	1	10.9	1	10.9
16	Ajaokuta	0.99117	8.31	0.99117	8.31	0.99117	8.31	0.99117	8.31
17	Delta IV	1	14.09	1	14.09	1	14.09	1	14.09
18	Aladja	0.99379	12	0.99379	12	0.99379	12	0.99379	12
19	Onitsha	0.93172	15.74	0.93172	15.74	0.93172	15.74	0.93172	15.74
20	Okpai	1	18.8	1	18.8	1	18.8	1	18.8
21	New Haven	0.88483	12.4	0.88483	12.4	0.88483	12.4	0.88483	12.4
22	Alaoji	0.93614	10.01	0.93614	10.01	0.93614	10.01	0.93614	10.01
23	Afam	1	9.28	1	9.28	1	9.28	1	9.28
24	Shiroro	0.90822	-9.56	0.90822	-9.56	0.90822	-9.56	0.90822	-9.56
25	Kano	0.43953	-41.84	0.43953	-41.84	0.43953	-41.84	0.43953	-41.84
26	Kaduna	0.64409	-22.19	0.64409	-22.19	0.64409	-22.19	0.64409	-22.19
27	Jos	0.47947	-35.21	0.47947	-35.21	0.47947	-35.21	0.47947	-35.21
28	Gombe	0.36216	-49.13	0.36216	-49.13	0.36216	-49.13	0.36216	-49.13

Table 4.8: Voltage Magnitudes and Angles for L-L Faults on Buses 27 and 28

Bus No.	Bus Name	Bus 27		Bus 28	
		Phase Volt A	Phase Ang A	Phase Volt A	Phase Ang A
1	BirninKebbi	0.91829	14.89	0.91829	14.89
2	Kainji GS	1	21.22	1	21.22
3	Jebba GS	1	14.62	1	14.62
4	Jebba TS	0.99364	14.09	0.99364	14.09
5	Oshogbo	0.95237	1.44	0.95237	1.44
6	Ayede	0.95812	-3.34	0.95812	-3.34
7	Papalanto	1	-2.98	1	-2.98
8	Ikeja West	0.955	-3.21	0.955	-3.21
9	Akangba	0.90079	-5.65	0.90079	-5.65
10	Egbin	1	0	1	0
11	Aja	0.95785	-2.57	0.95785	-2.57
12	Katampe	0.81797	-18.06	0.81797	-18.06
13	Omotosho	1	9.93	1	9.93
14	Benin	0.97733	8.88	0.97733	8.88

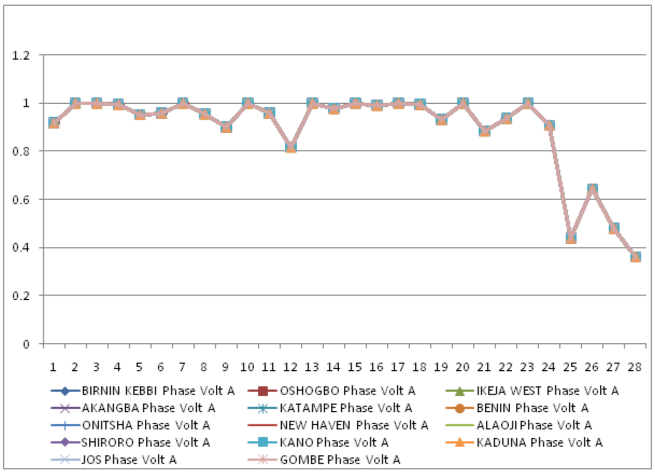

Figure 6: Voltage profiles resulting from simulation of line to line fault at buses 1, 5, 8, 9, 12, 14, 19, 21, 22, 24, 25, 26, 27 and 28

Double Line-To-Ground Fault Simulation

The bus voltages after the simulation of DLG are shown in tables 4.9-4.12 for the selected buses 1, 5, 8, 9, 12, 14, 19, 21, 22, 24, 25, 26, 27 and 28. The bus voltages after the simulation of DLG fault are shown in Figure 7. The voltages were very high in all the 28 buses when bus 5, 8, 9, and 12 are simulated for DLG fault. Also for each of the faulted buses 1, 25, 27 and 28, all the 28 buses in the test system recorded very low voltage values. Only buses 5 and 9 are within the acceptable voltage limits in the network. Detailed analyses are as shown in table 6. The highest voltage of 2.516 per units was recorded at bus 28 when bus 5 was subjected to the fault.

Table 4.9: Voltage Magnitudes and Angles for DLG Faults on Buses 1, 5, 8 and 9

Bus No.	Bus Name	Bus 1		Bus 5		Bus 8		Bus 9	
		Phase Volt A	Phase Ang A	Phase Volt A	Phase Ang A	Phase Volt A	Phase Ang A	Phase Volt A	Phase Ang A
1	BirninKebbi	1.0872	16.07	0.6067	-19.09	0.6205	1.54	0.6910	9.66
2	Kainji GS	0.9292	19.89	0.6300	-5.09	0.6940	12.92	0.7767	18.74
3	Jebba GS	0.8708	11.69	0.6795	-14.68	0.7089	3.51	0.7803	10.25
4	Jebba TS	0.8644	11.05	0.6776	-15.8	0.7032	2.61	0.7736	9.52
5	Oshogbo	0.8476	-4.02	1.1685	-1.2	1.1273	-1.77	1.0701	-1.94
6	Ayede	0.8656	-9.27	1.2221	-3.48	1.2431	-3.24	1.1593	-4.85
7	Papalanto	0.9090	-8.5	1.2670	-2.93	1.3065	-2.39	1.2172	-4.16
8	Ikeja West	0.8641	-9.1	1.2302	-2.99	1.2792	-2.28	1.1853	-4.27
9	Akangba	0.8153	-12.19	1.1848	-4.59	1.233	-3.88	1.2021	-5
10	Egbin	0.9073	-5.11	1.2750	-0.17	1.3160	0.14	1.2225	-1.58
11	Aja	0.8700	-8.19	1.2401	-1.97	1.2805	-1.67	1.1863	-3.68
12	Katampe	0.6357	-40.43	1.3460	-104.8	0.7377	-102.5	0.4731	-80.13
13	Omotosho	0.8996	6.17	1.2576	7.76	1.2728	7.4	1.1858	6.51
14	Benin	0.8741	4.72	1.2506	6.73	1.2626	6.3	1.1717	5.33
15	Sapele	0.8970	7.16	1.2652	8.49	1.2770	8.05	1.1878	7.22
16	Ajaokuta	0.8832	3.92	1.2840	6.11	1.2950	5.64	1.1981	4.62
17	Delta IV	0.8939	10.74	1.2612	11.03	1.2726	10.57	1.1832	9.93
18	Aladja	0.8894	8.35	1.2603	9.36	1.2717	8.88	1.1816	8.1
19	Onitsha	0.8376	12.75	1.1866	12.72	1.1908	11.88	1.1042	11.27
20	Okpai	0.9059	16.29	1.2487	15.67	1.2526	14.86	1.1672	14.41
21	New Haven	0.7935	8.78	1.1523	10.03	1.1553	9.07	1.0666	8.18
22	Alaoji	0.8726	6.23	1.1715	10.36	1.1728	9.5	1.0997	8.17
23	Afam	0.9395	5.71	1.2313	10	1.2332	9.19	1.1619	7.85
24	Shiroro	0.6799	-26.95	1.1954	-99.72	0.6081	-91.78	0.4193	-58.96
25	Kano	0.4980	-96.39	2.0290	-126.1	1.2865	-136.9	0.8205	-138.0
26	Kaduna	0.4924	-61.56	1.7154	-118.6	0.9828	-126.2	0.5572	-119.5
27	Jos	0.5030	-95.76	2.2541	-127.6	1.4095	-139.3	0.87784	-141.31
28	Gombe	0.56368	-114.81	2.51616	-131.66	1.64298	-144.6	1.07861	-148.88

Table 4.10: Voltage Magnitudes and Angles for DLG Faults on Buses 12, 14, 19 and 21

Bus No.	Bus Name	Bus 12		Bus 14		Bus 19		Bus 21	
		Phase Volt A	Phase Ang A	Phase Volt A	Phase Ang A	Phase Volt A	Phase Ang A	Phase Volt A	Phase Ang A
1	BirninKebbi	1.52537	-61.84	0.69463	3.02	0.78269	8.88	0.81866	11.77
2	Kainji GS	1.37069	-55.31	0.76702	13.14	0.8621	17.17	0.9014	19.29

3	Jebba GS	1.4938	-57.05	0.7818	4.61	0.86937	9.54	0.90469	11.98
4	Jebba TS	1.50569	-57.59	0.77614	3.8	0.86322	8.87	0.89829	11.37
5	Oshogbo	1.93935	-68.55	1.10675	-0.33	1.05264	0.4	1.02078	0.25
6	Ayede	2.04553	-69.84	1.1799	-2.56	1.09954	-2.82	1.05675	-3.6
7	Papalanto	2.03526	-68.3	1.23392	-1.85	1.14891	-2.23	1.1041	-3.09
8	Ikeja West	2.03964	-69.88	1.20013	-1.78	1.11078	-2.27	1.06404	-3.22
9	Akangba	2.06184	-71.78	1.15057	-3.56	1.05901	-4.28	1.01186	-5.41
10	Egbin	1.96422	-67.3	1.2633	1.41	1.16722	0.93	1.11695	-0.04
11	Aja	1.99529	-69.02	1.22516	-0.47	1.12724	-1.2	1.07676	-2.33
12	Katampe	1.20197	-50.12	0.71269	-85.41	0.61811	-56.58	0.60646	-40.75
13	Omotosho	1.70953	-63.87	1.31748	10.66	1.20286	10.51	1.14149	9.53
14	Benin	1.77975	-66.29	1.31912	9.91	1.19526	9.68	1.12951	8.57
15	Sapele	1.71839	-64.38	1.33374	11.48	1.21305	11.37	1.14836	10.38
16	Ajaokuta	1.87119	-67.84	1.35575	9.41	1.22297	9.14	1.15289	7.98
17	Delta IV	1.6586	-63.8	1.33234	13.89	1.21227	14.01	1.147	13.17
18	Aladja	1.70311	-64.56	1.33007	12.33	1.20838	12.28	1.1429	11.33
19	Onitsha	1.46102	-62.74	1.25046	15.38	1.25893	17.35	1.16177	15.67
20	Okpai	1.42391	-58	1.31298	18.07	1.32194	19.91	1.2259	18.44
21	New Haven	1.51947	-65.36	1.21383	12.96	1.2219	15.14	1.18833	13.76
22	Alaoji	1.49758	-50.44	1.21294	13.19	1.21585	15.18	1.13637	12.7
23	Afam	1.54166	-47.3	1.27035	12.7	1.27179	14.59	1.19532	12.13
24	Shiroro	1.5314	-56.66	0.62806	-72.08	0.62162	-40.91	0.65354	-26.33
25	Kano	1.66812	-78.94	1.09062	-126.79	0.68114	-113.29	0.48152	-102.63
26	Kaduna	1.65694	-70.25	0.84698	-111.71	0.55635	-85.5	0.4536	-64.46
27	Jos	1.86257	-78.67	1.18045	-128.87	0.70893	-114.77	0.48107	-102.77
28	Gombe	1.9188	-83.19	1.37325	-135.93	0.8349	-127.45	0.56372	-122.26

Table 4.11: Voltage Magnitudes and Angles for DLG Faults on Buses 22, 24, 25 and 26

Bus No.	Bus Name	Bus 22		Bus 24		Bus 25		Bus 26	
		Phase Volt A	Phase Ang A	Phase Volt A	Phase Ang A	Phase Volt A	Phase Ang A	Phase Volt A	Phase Ang A
1	BirninKebbi	0.83857	10.63	1.63631	-6.75	0.22848	-1.53	1.38212	-12.86
2	Kainji GS	0.91811	18.16	1.63095	-1.35	0.34542	22.68	1.37336	-6.06
3	Jebba GS	0.92378	10.98	1.68104	-5.22	0.34877	3.66	1.42898	-10.49
4	Jebba TS	0.91763	10.37	1.6815	-5.66	0.34118	1.86	1.42941	-11.02
5	Oshogbo	1.02247	1.1	1.85388	-15.37	0.27971	-55.17	1.59811	-23.33
6	Ayede	1.05292	-2.51	1.89695	-17.89	0.34311	-65.45	1.65093	-26.24
7	Papalanto	1.09938	-2	1.9226	-17.27	0.36257	-57.41	1.67738	-25.3
8	Ikeja West	1.05868	-2.04	1.89138	-17.85	0.33872	-65.74	1.64639	-26.23
9	Akangba	1.00535	-4.16	1.85248	-19.44	0.35398	-77.31	1.61553	-28.3
10	Egbin	1.11126	1.16	1.89471	-15.63	0.32437	-50.35	1.6467	-23.47
11	Aja	1.06982	-1.08	1.86944	-17.29	0.3344	-61.49	1.62882	-25.53
12	Katampe	0.68315	-41.11	1.42799	-21.88	0.58738	-51.22	1.26765	-27.84
13	Omotosho	1.13669	11	1.78813	-10	0.24456	-14.47	1.53135	-16.96
14	Benin	1.12378	10.16	1.80849	-11.37	0.20404	-25.91	1.54554	-18.79
15	Sapele	1.14358	11.91	1.79733	-9.74	0.22431	-12.24	1.53476	-16.76
16	Ajaokuta	1.14658	9.65	1.87159	-12.24	0.18609	-34.17	1.59688	-19.92
17	Delta IV	1.14373	14.71	1.77369	-8.02	0.21043	2.06	1.50591	-14.83
18	Aladja	1.13855	12.88	1.78751	-9.29	0.2087	-8.42	1.52242	-16.31
19	Onitsha	1.15399	18.07	1.60907	-6.92	0.21627	12.81	1.36471	-13.43
20	Okpai	1.21941	20.67	1.64759	-3.57	0.29644	21.13	1.40049	-9.41
21	New Haven	1.11149	15.59	1.59503	-9.47	0.16983	-5.76	1.35657	-16.6
22	Alaoji	1.26267	12.4	1.56871	-3.92	0.39527	-15.18	1.38176	-10.38
23	Afam	1.31983	12.06	1.62725	-3.2	0.4744	-13.61	1.44444	-9.34
24	Shiroro	0.72538	-28.1	1.51725	-16.39	0.60242	-35.65	1.33212	-21.52
25	Kano	0.54435	-93.6	1.14994	-31.24	0.48505	-51.54	0.83435	-40.56
26	Kaduna	0.54447	-61.21	1.35913	-24.06	0.51389	-56.97	1.03851	-29.34
27	Jos	0.5551	-92.75	1.30805	-28.92	0.50844	-87.09	0.93703	-37.19
28	Gombe	0.60877	-110.79	1.21063	-31.86	0.54447	-105.28	0.82874	-42.89

Table 4.12: Voltage Magnitudes and Angles for DLG Faults on Buses 27 and 28

Bus No.	Bus Name	Bus 27		Bus 28	
		Phase Volt A	Phase Ang A	Phase Volt A	Phase Ang A
1	BirninKebbi	0.58189	-54.02	0.66854	27.84
2	Kainji GS	0.52201	-35.12	0.78505	33.32
3	Jebba GS	0.61762	-42.29	0.76081	25.09
4	Jebba TS	0.62178	-43.62	0.7519	24.58
5	Oshogbo	0.82858	-70.93	0.61881	12.23
6	Ayede	0.91555	-73.92	0.60319	5.34
7	Papalanto	0.91795	-70.58	0.6498	5.16
8	Ikeja West	0.91132	-74.11	0.60054	5.65
9	Akangba	0.93514	-78.36	0.53919	2.61
10	Egbin	0.86224	-68.56	0.66219	9.5
11	Aja	0.89087	-72.47	0.61185	6.3
12	Katampe	0.89293	-57.84	0.62494	-21.54
13	Omotosho	0.67324	-59.91	0.71389	22.78
14	Benin	0.69536	-65.71	0.67739	22.66
15	Sapele	0.66189	-61	0.71332	24.48
16	Ajaokuta	0.72724	-69.19	0.67512	22.83
17	Delta IV	0.60767	-59.14	0.72783	28.7
18	Aladja	0.64264	-61.34	0.71106	26.17
19	Onitsha	0.52171	-55.31	0.69498	30.39
20	Okpai	0.51707	-44.17	0.77224	32.37
21	New Haven	0.56195	-62.93	0.63348	27.29
22	Alaoji	0.71236	-43.14	0.69179	17.08
23	Afam	0.77597	-38.77	0.75562	15.01
24	Shiroro	0.87942	-47.36	0.71404	-10.21
25	Kano	0.74114	-80.11	0.33642	-60.6
26	Kaduna	0.77116	-59.95	0.50104	-28.42
27	Jos	0.62507	-53.44	0.45432	-42.41
28	Gombe	0.53557	-61.83	0.44593	-49.28

Table 6: Detail analysis of the results obtained for SLG fault

Faulted Bus	Low Voltage Bus	High Voltage Bus	Bus within $\pm 5\%$ $Limit$
1	(27 buses)	1 (1 bus)	None
5	1, 2, 3 and 4 (4 buses)	(The rest 24 buses)	None
8	1, 2, 3, 4, 12 and 23 (6 buses)	The other 21 buses	Bus 9 (1 bus)
9	1, 2, 3, 4, 12, 24, 25, 26 and 27 (9 buses)	The other 19 buses	None
12	None	All the 28 buses	None
14	1, 2, 3, 4, 12, 24 and 26 (7 buses)	The Other 21 buses	None
19	(10 buses)	(17 buses)	Only bus 5
21	(10 buses)	(17 buses)	Only bus 5
22	10 buses	(18 buses)	None
24	None	All the 28 buses	None
25	All the 28 buses	None	None
26	25, 27 and 28 (3 buses)	The other 24 buses	None
27	All the 28 buses	None	None
28	All the 28 buses	None	None

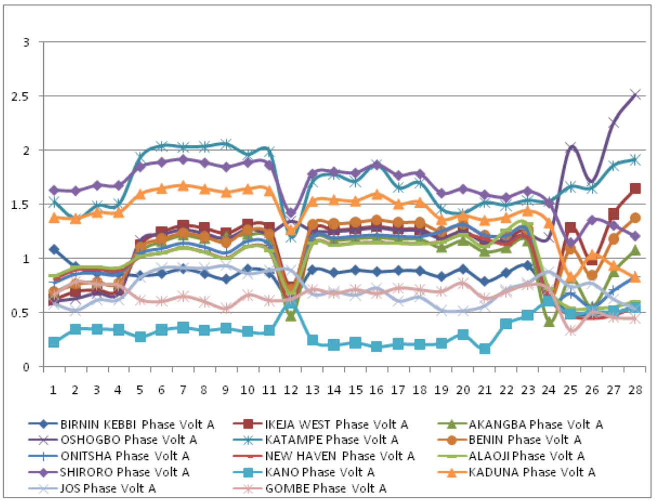

Figure 7: Voltage profiles resulting from simulation of double line to ground fault at buses 1, 5, 8, 9, 12, 14, 19, 21, 22, 24, 25, 26, 27 and 28

Recommendations

Based on the results obtained in this work, the following should be taken into consideration to improve the quality of power transmission and reduce transmission challenges in Nigeria:

- Provision of two double-circuit transmission lines to interconnect Katampe and Shiroro because a DLG fault on any of these buses produced a high voltage in all the 28 buses,and also double-circuit lines to connect Kainji to B/Kebbi, Oshogbo to Ikeja-West, Oshogbo to Benin, Kaduna to Kano will greatly enhance the efficiency of the test system.
- Provision of multiple loops by introducing more substations and additional line in the network especially the Northern buses (i.e Kaduna, Jos and Gombe) with record of high voltage drops (low bus voltage) in all the 28 buses.
- To help in fast fault isolation and clearance, good protective systems should be installed at several points on the transmission network. The aim of the protection scheme is to ensure power system stability and reliability by isolating only the faulted part. Fault clearance response time should be fast so as to ensure quick restoration of supply to consumers
- Scheduled maintenance should be carried out on the transmission network to help prevent total collapse of the system.
- There is urgent need to reconfigure or upgrade the over aged power lines to enhance voltage stability and efficiency in the system.
- High rated shunt capacitors should be placed at the voltage violating buses for compensation tohelp improve the voltage magnitude of these buses

Conclusion

The various causes and effects of power faults have been analysed in this paper. The load-flow analysis performed showed very low voltage magnitudes at Birnin-Kebbi, Akangba, Katampe, Onitsha, New Haven, Alaoji, Shiroro, Kano, Kaduna, Jos and Gombe. These results reveal the reality of the terrible state of the power supply in Nigeria. The fault analysis also showed the need for proper protection of the system to ensure security of the network. The implication of the results obtained from this research work is that the existing Nigerian transmission system is vulnerable and the system could suffer from voltage instability, failure or outage, high voltage drops (voltage sag) as well as low efficiency as revealed from the results obtained in section 4. Faults in the system are the most frequent cause of voltage sags. Information gained from this study can be used for power system design, planning and proper protection of the Nigerian grid.

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