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Power Transmission Constraints and Faults Analysis in the Nigeria Power System

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Abstract: This study presents the analysis of various aspects of power transmission constraints associated with the Nigerian grid. The different types of short circuit faults were also simulated into the network using the Power World Simulator (PWS), to examine their effects on the bus voltages and currents. The study revealed that the Nigeria power transmission network is characterised by forced and emergency outages leading to very low power reliability and efficiency. This phenomenon have adversely affected the economic growth in the country and also caused great disruption in the lives of the citizens. Recommendations to reduce these constraints are proffered in this study to ensure good power quality and security in the network.

Key words: Voltage, outage, buses, power world simulator, transmission, faults

INTRODUCTION

The Transmission Network in Nigeria is characterised by several outages leading to disruption in the lives of the citizenry. The level of disruption is a function of the dependency of people on electricity, which can be very high for a developed country and not as much as developing countries (Anil *et al*., 2007). In Nigeria, the available energy generated is not enough to meet the demands of the users leading to constant load shedding and blackouts. Outages can be planned or forced. In Nigeria, the National Control Centre (NCC) as stipulated in Operational Procedure No. 10 (OP 10) (PHCN, 2006), power stations and transmission are required to forward their planned outages schedules for the following year to NCC, latest by end of the month of November. This enables the NCC to plan a master programme of planned outages properly co-ordinated to ensure maintenance of Grid integrity after a thorough study and analysis of the various outages. Forced outages can be associated with aging equipment/defects, lightning, wind, birds/animals, vandalization, accidents and poor job execution by contractors etc. However, forced outages can be minimised if the system is properly designed and maintained but this will not completely eliminate interruptions. The objective of this study, is to examine the various factors militating against effective power transmission in Nigeria and make recommendations to improve the efficiency of the network.

MATERIALS AND METHODS

The methodology adopted for this study is as follows;

- The overview of the 330KV and 132KV Nigeria transmission network.
- Data collation on transmission constraints based on PHCN annual reports for 2003, 2004 and 2005 and logbooks.
- Load flow analysis using the Power World Simulator software (1996-2000) to assess the existing state of the networks.
- Simulation of various aspects of faults on the test system.
- Analysis of power outages in the networks.

FAULTS ASSOCIATED WITH TRANSMISSION LINES

Several types of faults occur in transmission systems. These could be short circuit or open-circuit. Short circuits occur in power systems when equipment insulation fails due to system over voltages caused by lightning or switching surges, insulation contamination or to other mechanical causes (Glover and Sarma, 2002). Short circuits faults may be several orders of magnitude larger than normal operating currents and if allowed to persist, may cause thermal damages to equipment. If short circuits faults are not interrupted promptly, electrical fire and explosions can occur.

In three phase circuits, the frequency of occurrence of short circuit faults is in the order of single line-to-ground, line-to-line, double line-to-ground and balanced three phase faults (Power World Co-operation). The path of the fault may have either zero impedance, (bolted short-circuit) or non-zero impedance. The various types of faults are as illustrated in Fig. 1 (Power World Co-operation).

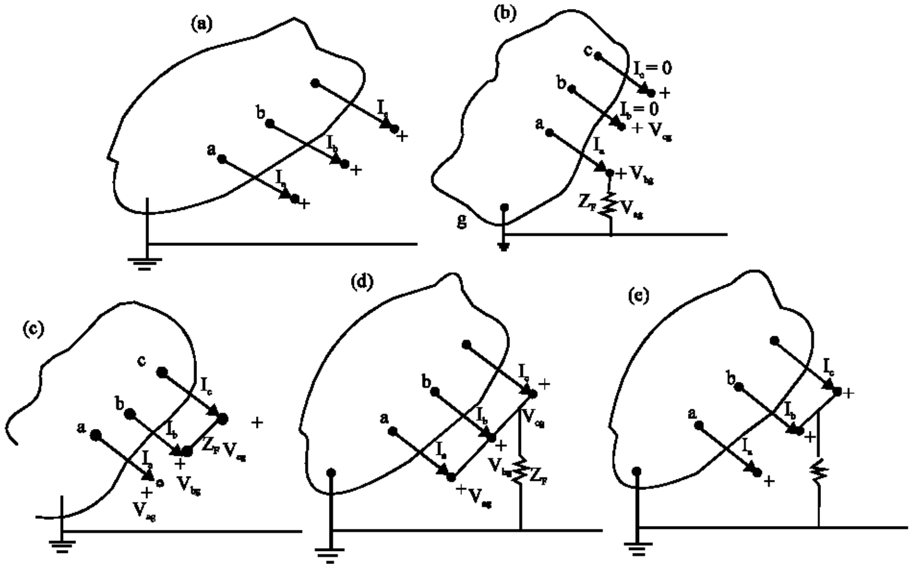

Fig. 1: Types of faults

Table 1: Bus identification

Bus number	Bus name	Bus number	Bus name
1	Oshogbo	15	Aladja
2	Benin	16	Kano
3	Ikj-West	17	SAP P/S
4	Ayede	18	Aja
5	Jos	19	Ajaokuta
6	Onitsha	20	N Haven
7	Akangba	21	Alaoji
8	Gombe	22	AFAMGS
9	Abuja	23	Jebba
10	Egbin-PS	24	JebbaGS
11	DELTA PS	25	KAINJIGS
12	AES	26	B Kebbi
13	Okpai	27	Shiroro
14	Calabar	28	Kaduna

Open circuit can also occur when one-conductor-open, or two-conductor-open arising from breakage of conductors or when one or two phases of a circuit breaker inadvertently open.

TEST SYSTEM FOR TRANSMISSION CONSTRAINTS AND FAULT ANALYSIS

The power stations in Nigeria are mainly hydro and thermal plants. Power Holding Company of Nigeria (PHCN) generating plants sum up to 6200MW out of which 1920 MW is hydro and 4280 MW are thermal-mainly gas fired1 (Sadoh, 2005). The Nigerian Electricity Network comprises 11,000 km transmission lines (330 kV and 132 kV), 24000 km of sub-transmission line (33 kV), 19000 km of distribution line (11 kV) and 22,500 substations (Sadoh, 2005). It has only one major loop system involving Benin-Ikeja West-Ayede-Oshogbo and Benin. The absence of loops accounts mainly for the weak and unreliable power system in the country. The single line diagram of the existing 28 bus 330 kV Nigerian transmission network used as the test system for the case study is shown in Fig. 1 as well as bus identification shown in Table 1.

SIMULATION AND ANALYSIS OF RESULTS OF VARIOUS ASPECTS OF FAULTS ON THE TEST SYSTEM

The test system shown in Fig. 2 was redrawn using the edit mode in the Power World Simulator (PWS) as shown in Fig. 3. Load flow analysis to determine the bus voltage, active and reactive power flow and losses on the various lines under normal conditions was carried out. The bus voltages, line flows and power losses under normal operating condition are shown in Table 2 and 3, respectively. The scenarios considered in this analysis include single phase to ground fault, line to line fault,

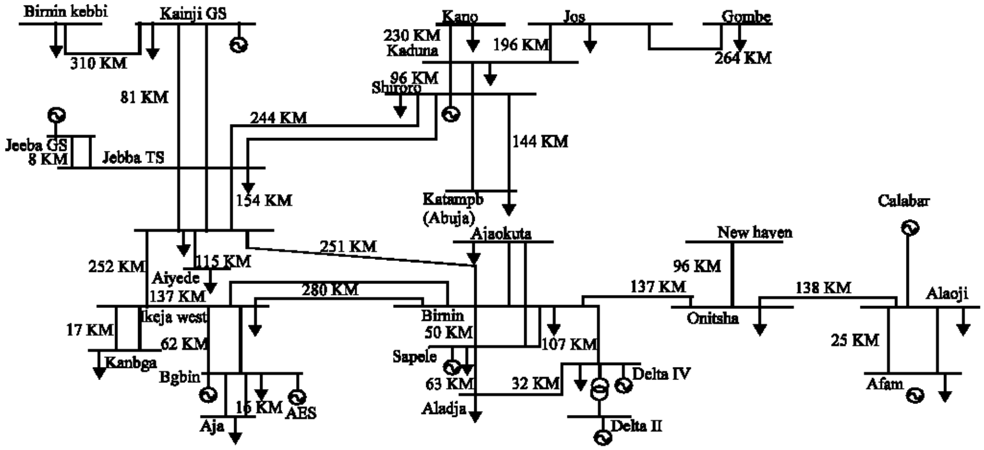

Fig. 2: The Nigerian 330KV transmission grid used for the case study

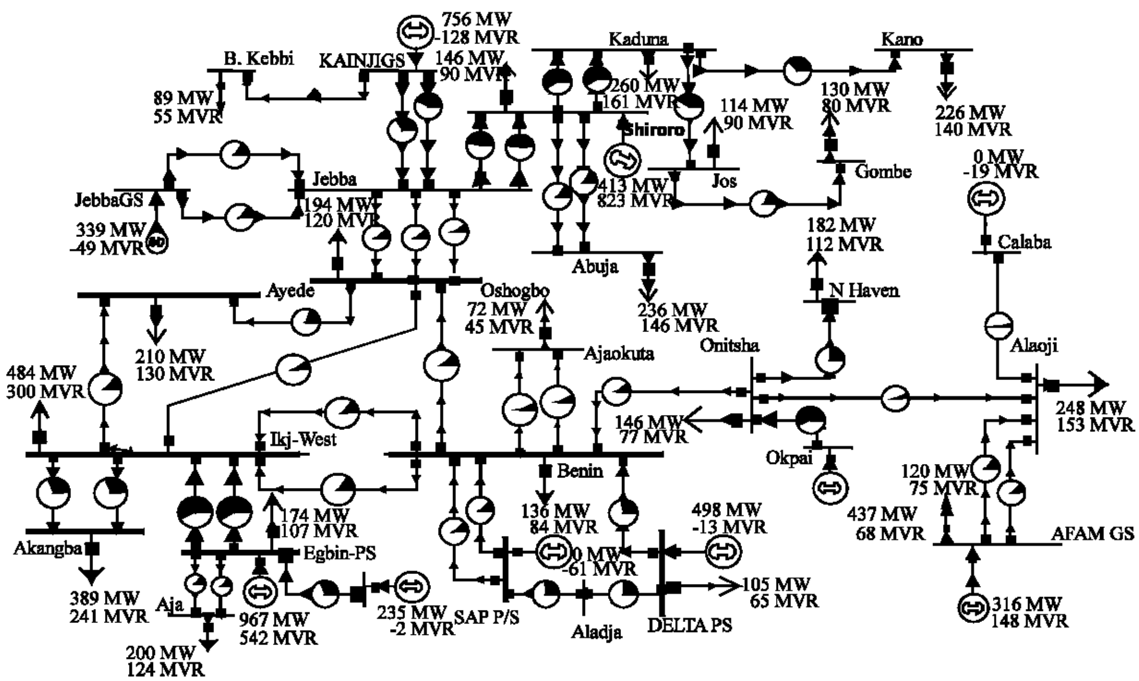

Fig. 3: The Nigeria 330kVTransmission Network (Simulated in the run mode)

Table 2: Bus records under normal operating conditions

Nr	PU Volt	Volt (kV)	Angle (Deg)
1	0.98986	326.654	-6.85
2	1.0018	330.593	-3.32
3	0.9637	318.021	-6.87
4	0.95534	315.263	-9.04
5	0.76078	251.056	-39.42
6	0.98046	323.553	-1.95
7	0.95589	315.444	-7.46
8	0.65964	217.681	-50.8
9	0.97119	320.492	-24.11
10	1	330	-2.85
11	1	330	0.54
12	1	330	-2.85
13	1	330	2.31
14	1	330	-5.19

Table 2: Continued

Nr	PU Volt	Volt (kV)	Angle (Deg)
15	1.0008	330.265	-1.56
16	0.74893	247.148	-40.36
17	1	330	-2.55
18	0.99362	327.894	-3.36
19	1.00759	332.504	-4.52
20	0.95624	315.56	-5.1
21	0.96416	318.174	-5.17
22	1	330	-1.31
23	1	330	-4.75
24	1	330	-4.53
25	1	330	0
26	0.98364	324.603	-4.87
27	1	330	-21.2
28	0.90349	298.153	-27.68

double line to ground fault and 3 phase balanced faults. These faults were simulated at buses 1, 2 and 3. Bus 1 was selected because it is the major bus linking the southern and northern parts of the grid and also the location of the National Control Centre (NCC). Bus 2 represents the bus which links the eastern, western and northern parts of the network. Bus 3 is the highest loaded bus in the entire network and also tied to the highest generating stations located at Egbin and AES.

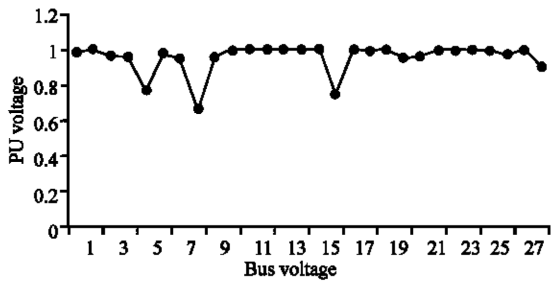

Fig. 4: Voltage profiles under normal conditions

Singe line to ground fault: The bus voltages after the simulation are shown in Table 4 for buses 1, 2 and 3 as well as Fig. 5. The results showed low voltage values at bus 4,9,16,23,24,26,27 and 28 when bus 1 was subjected to single line to ground fault. The highest voltage of 2.52 per-units was recorded at bus 8, when bus 2 was subjected to the fault.

Line to line fault: The bus voltages after the simulation are shown In Table 5 for buses 1, 2 and 3 as well as Fig. 6. This scenario showed that most of the bus voltages are within limits except bus 5, 8 and 16.

Table 3: Line flows and power losses under normal operating condition

From Nr	To Nr	From MW	From Mvar	From MVA	Lim MVA	Max percent	MW loss	Mvar loss
28	16	235.4	160.1	284.7	760	37.5	9.42	20.09
28	27	-376.6	-249.8	451.9	760	63.2	8.21	37.43
28	5	257.8	178.6	313.6	760	41.3	9.45	28.68
28	27	-376.6	-249.8	451.9	760	63.2	8.21	37.43
27	9	118.9	27.1	121.9	760	18.3	0.89	-45.95
27	9	118.9	27.1	121.9	760	18.3	0.89	-45.95
27	23	-370.2	52.3	373.9	760	50.6	12.77	16.2
27	23	-370.2	52.3	373.9	760	50.6	12.77	16.2
26	25	-89	-55	104.6	760	13.8	0.91	-98.39
25	23	333.3	-42.1	335.9	760	44.2	3.35	-3.3
25	23	333.3	-42.1	335.9	1000	33.6	3.35	-3.3
24	23	169.5	-24.4	171.2	1000	17.1	0.09	-2.66
24	23	169.5	-24.4	171.2	1000	17.1	0.09	-2.66
23	1	77.6	-16.3	79.3	760	11.4	0.35	-56.14
23	1	77.6	-16.3	79.3	760	11.4	0.35	-56.14
23	1	77.6	-16.3	79.3	760	11.4	0.35	-56.14
21	22	-97	-38.6	104.4	760	13.8	1.02	-2.09
21	22	-97	-38.6	104.4	760	13.8	1.02	-2.09
20	21	0.5	-42.1	42.1	1000	4.2	0.02	-48.16
19	2	-36	-22.5	42.5	760	8.3	0.11	-74.36
15	17	187.7	-17.5	188.5	760	24.8	0.38	-8.55
15	11	-187.7	17.5	188.5	760	25.2	0.81	-17.8
14	21	0	-19.3	19.3	760	4.4	0	-53.05
10	18	100.1	52.8	113.2	760	15.5	0.13	-9.18
10	18	100.1	52.8	113.2	760	15.5	0.13	-9.18
10	12	-235	2.4	235	760	30.9	0	0.01
10	3	413.9	169.2	447.1	760	58.8	4.49	32.06
6	21	53.7	-10.4	54.7	760	8.5	0.16	-46.31
6	20	183.8	47.2	189.8	760	25.7	1.34	-22.69
6	13	-433.1	-56.3	436.7	760	58.2	3.95	12.05
5	8	134.3	59.9	147.1	760	20.1	4.34	-20.09
4	3	-97.1	-30.8	101.9	760	13.4	0.51	-44.21
4	1	-112.9	-99.2	150.3	760	19.8	0.85	-34.07
3	2	-74.1	-85.1	112.9	760	14.9	0.77	-106.3
3	10	-409.4	-147.9	435.3	760	58.3	4.49	9.76
3	7	194.8	122.9	230.4	760	30.3	0.34	2.42
3	7	194.8	122.9	230.4	760	30.3	0.34	2.42
3	2	-74.1	-85.1	112.9	760	14.9	0.77	-106.32
3	1	-4.3	-77.1	77.2	760	10.2	0.1	-92.33
2	19	36.1	-51.9	63.2	760	8.3	0.11	-74.36
2	17	-93.5	15.3	94.7	760	13.1	0.17	-19.54
2	17	-93.5	15.3	94.7	760	13.1	0.17	-19.54
2	11	-202.9	15.9	203.5	760	27.5	1.62	-27.22
2	6	-49.2	54.8	73.7	760	10	0.28	-2.73
1	2	-80.4	-50.4	94.9	760	12.5	0.59	-89.56

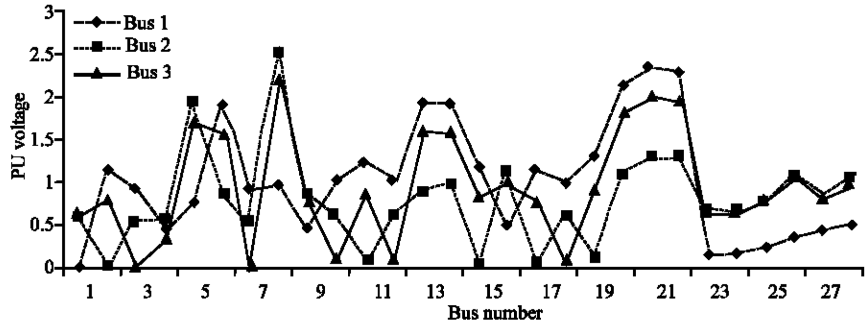

Fig. 5: Voltage profiles for single line to ground fault at buses 1, 2 and 3

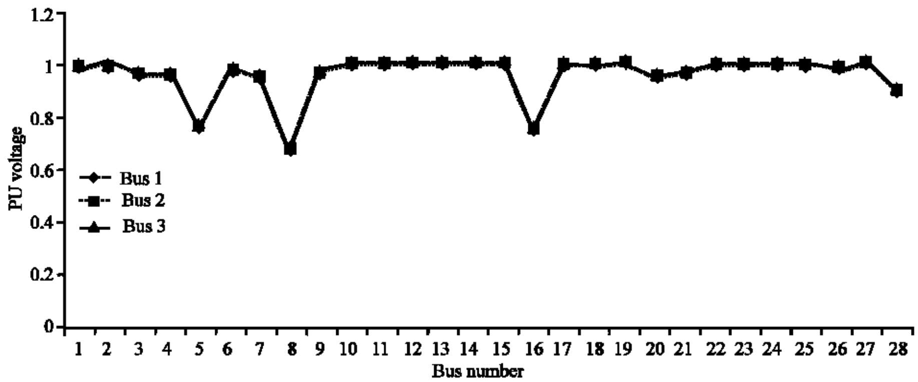

Fig. 6: Voltage profiles resulting from simulation of line to line fault at bus 1, 2 and 3

Table 4: per unit values of voltages for single line to ground fault

Bus number	Name	BUS 1 Phase Volt A	BUS 1 Phase Ang A	BUS 2 Phase Volt A	BUS 2 Phase Ang A	BUS 3 Phase Volt A	BUS 3 Phase Ang A
1	Oshogbo	0	0	0.58425	62.6	0.58216	57.83
2	Benin	1.15079	50.96	0	0	0.77113	70.52
3	Ikj-West	0.92675	50.96	0.54899	76.25	0	0
4	Ayede	0.48043	52.98	0.602	72.76	0.32248	64.08
5	Jos	0.77761	-82.88	1.96149	-74.78	1.69654	-78.35
6	Onitsha	1.91411	49.25	0.85703	89	1.57051	72.64
7	Akangba	0.92365	50.97	0.54772	76.93	0.00757	155.24
8	Gombe	0.9684	-90.81	2.51705	-80.59	2.18795	-85.06
9	Abuja	0.44338	-47.64	0.8871	-42.05	0.79506	-40.81
10	Egbin-PS	1.02476	50.59	0.64422	72.83	0.11487	57.34
11	DELTA PS	1.21977	52.47	0.09733	85.08	0.85224	71.41
12	AES	1.02476	50.59	0.64422	72.83	0.11489	57.34
13	Okpai	1.93886	49.94	0.89549	86.9	1.60167	72.21
14	Calaba	1.90709	41.47	0.98166	73.63	1.55707	63.18
15	Aladja	1.18922	51.64	0.05126	85.01	0.81521	70.99
16	Kano	0.50257	-70.82	1.15138	-63.62	1.01022	-65.33
17	SAP P/S	1.16446	51.21	0.02173	80.34	0.78783	70.62
18	Aja	1.02379	50.56	0.64427	73.33	0.11444	60.49
19	Ajaokuta	1.29043	51.11	0.12643	104.31	0.90771	72.79
20	N Haven	2.1433	48.43	1.11569	90.36	1.80779	73.25
21	Alaoji	2.30671	47.82	1.29553	89.21	1.97221	72.79
22	AFAM GS	2.28792	47.42	1.29731	85.95	1.94951	71.07
23	Jebba	0.15749	29.1	0.64446	46.6	0.6476	43.92
24	JebbaGS	0.15994	29.9	0.64638	46.69	0.64953	44.03
25	KAINJIGS	0.24976	51.18	0.78593	53.84	0.77974	50.72
26	B Kebbi	0.37527	55.99	1.10947	61.56	1.06601	56.39
27	Shiroro	0.44491	-44.94	0.88165	-39.74	0.79015	-38.22
28	Kaduna	0.49876	-60.22	1.09597	-55.4	0.95708	-55.83

Table 5: Per unit bus voltages after simulation of line to line fault at bus 1,2 and 3

Bus numbers	Name	BUS 1 Phase Volt A	Phase Ang A	BUS 2 Phase Volt A	Phase Ang A	BUS 3 Phase Volt A	Phase Ang A
1	Oshogbo	0.98985	-6.85	0.98985	-6.85	0.98985	-6.85
2	Benin	1.00179	-3.32	1.00179	-3.32	1.00179	-3.32
3	Ikj-West	0.96369	-6.87	0.96369	-6.87	0.9637	-6.87
4	Ayede	0.95534	-9.04	0.95534	-9.04	0.95534	-9.04
5	Jos	0.76077	-39.42	0.76078	-39.42	0.76078	-39.42
6	Onitsha	0.98045	-1.95	0.98045	-1.95	0.98045	-1.95
7	Akangba	0.95588	-7.46	0.95588	-7.46	0.95588	-7.46
8	Gombe	0.65964	-50.8	0.65964	-50.8	0.65964	-50.8
9	Abuja	0.97118	-24.11	0.97119	-24.11	0.97119	-24.11
10	Egbin-PS	0.99999	-2.85	0.99999	-2.85	0.99999	-2.85
11	DELTA PS	0.99999	0.54	0.99999	0.54	0.99999	0.54
12	AES	0.99999	-2.85	0.99999	-2.85	0.99999	-2.85
13	Okpai	0.99999	2.31	0.99999	2.31	0.99999	2.31
14	Calaba	0.99999	-5.19	0.99999	-5.19	0.99999	-5.19
15	Aladja	1.00079	-1.56	1.00079	-1.56	1.00079	-1.56
16	Kano	0.74893	-40.36	0.74893	-40.36	0.74893	-40.36
17	SAP P/S	0.99999	-2.55	0.99999	-2.55	0.99999	-2.55
18	Aja	0.99361	-3.36	0.99361	-3.36	0.99361	-3.36
19	Ajaokuta	1.00758	-4.52	1.00758	-4.52	1.00758	-4.52
20	N Haven	0.95623	-5.1	0.95623	-5.1	0.95623	-5.1
21	Alaoji	0.96415	-5.17	0.96415	-5.17	0.96415	-5.17
22	AFAM GS	0.99999	-1.31	0.99999	-1.31	0.99999	-1.31
23	Jebba	0.99999	-4.75	0.99999	-4.75	0.99999	-4.75
24	JebbaGS	1	-4.53	0.99999	-4.53	0.99999	-4.53
25	KAINJIGS	0.99999	0	0.99999	0	0.99999	0
26	B Kebbi	0.98364	-4.87	0.98363	-4.87	0.98364	-4.87
27	Shiroro	1	-21.2	1	-21.2	1	-21.2
28	Kaduna	0.90349	-27.68	0.90349	-27.68	0.90349	-27.68

Table 6: Bus voltages due to double line to ground faults

Bus number	Name	BUS 1 Phase Volt A	Phase Ang C	BUS 2 Phase Volt A	Phase Ang A	BUS 3 Phase Volt A	Phase Ang A
1	Oshogbo	1.41008	0	1.5775	-23.92	1.56101	-33.65
2	Benin	1.95274	-95.58	1.70752	-21.29	1.71507	-31.21
3	Ikj-West	1.78291	-93.06	1.59024	-22.26	1.47399	-30.09
4	Ayede	1.62254	-85.35	1.59681	-24.71	1.53062	-33.67
5	Jos	0.2922	115.25	0.40504	-164.16	0.45138	151.86
6	Onitsha	2.61944	-91.55	1.93976	-21.88	2.11592	-34.73
7	Akangba	1.78011	-92.18	1.58271	-22.62	1.46606	-30.48
8	Gombe	0.6712	114.76	0.88369	172.58	1.00779	146.18
9	Abuja	0.69351	115.97	0.81367	-41.26	0.7049	-43.08
10	Egbin-PS	1.72414	-102.4	1.59215	-19.19	1.46122	-26.55
11	DELTA PS	1.88508	-99.84	1.67437	-18.97	1.67538	-28.97
12	AES	1.72409	-102.4	1.59213	-19.19	1.4612	-26.55
13	Okpai	2.49968	-94.6	1.90385	-19.32	2.05413	-32.27
14	Calaba	2.45703	-93.24	1.83826	-21.02	2.03449	-33.25
15	Aladja	1.93087	-97.36	1.69616	-20.24	1.70248	-30.25
16	Kano	0.37475	111.54	0.44126	-84.41	0.28166	-93.77
17	SAP P/S	1.93822	-96.41	1.69902	-20.8	1.70586	-30.75
18	Aja	1.72608	-101.44	1.58826	-19.53	1.45672	-26.9
19	Ajaokuta	2.15777	-91.86	1.79932	-22.45	1.84315	-33.07
20	N Haven	2.93136	-88.81	2.03714	-23.87	2.2935	-37.26
21	Alaoji	3.07947	-88.49	2.09435	-23.74	2.38947	-37.42
22	AFAM GS	2.87193	-91.2	2.02855	-20.93	2.28515	-34.43
23	Jebba	1.20939	154.58	1.43012	-23.48	1.38191	-32.47
24	JebbaGS	1.20565	155.07	1.42778	-23.31	1.37898	-32.29
25	KAINJIGS	1.17793	176.63	1.44528	-21.23	1.38773	-30.68
26	B Kebbi	1.35973	-136.81	1.67102	-28.02	1.64233	-38.75
27	Shiroro	0.72083	117.67	0.84554	-37	0.73967	-38.6
28	Kaduna	0.49008	115.69	0.56502	-51.03	0.42408	-48.81

The voltage profiles showed a great resemblance of the normal operating condition as shown in Fig. 6.

Double line to ground fault: The bus voltages after the simulation are shown in Table 6 for buses 1, 2 and 3 as

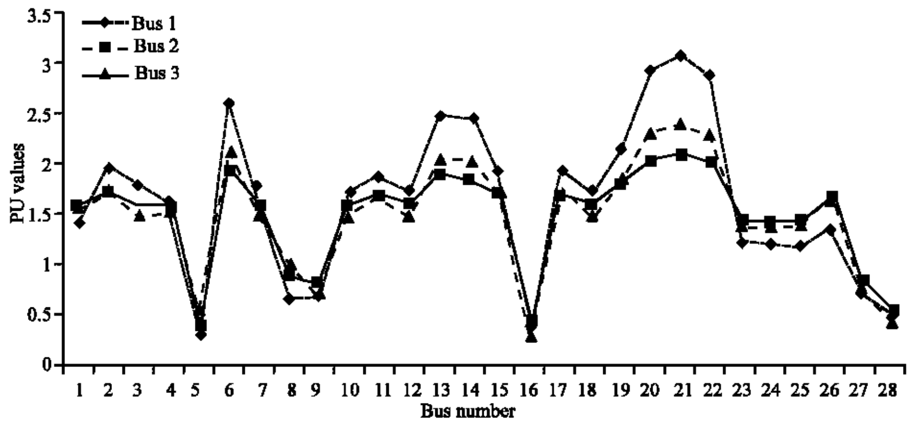

Fig. 7: Voltages profiles due to double line to ground faults

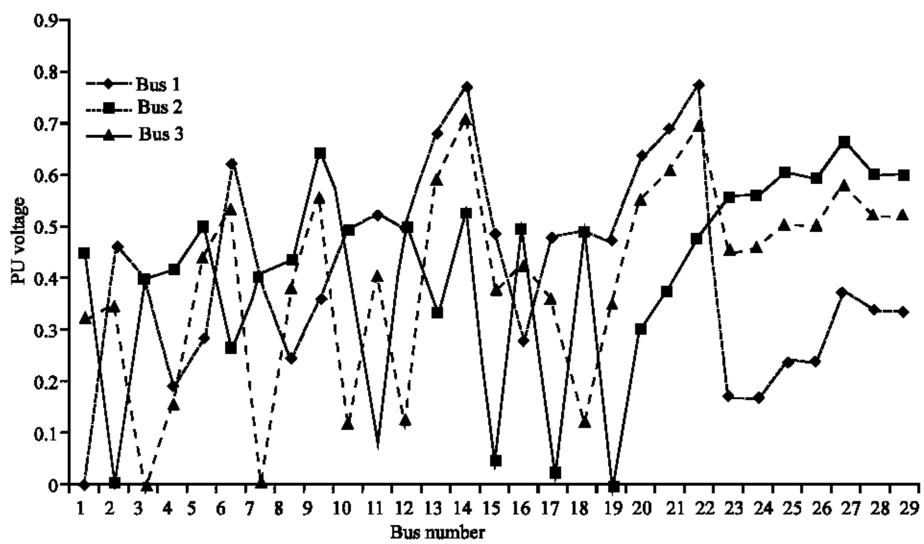

Fig. 8: Voltage profiles due to 3 phase faults

Table 7: Bus voltages due to 3 phase faults

Number	Name	BUS 1	BUS 2	BUS 3	Normal
1	Oshogbo	0	0.44713	0.32224	0.98084
2	Benin	0.46879	0	0.35007	0.99822
3	Ikj-West	0.39939	0.40471	0	0.93433
4	Ayede	0.19148	0.41672	0.16061	0.93552
5	Jos	0.28591	0.50531	0.4418	0.76078
6	Onitsha	0.62658	0.25996	0.53502	0.97954
7	Akangba	0.39615	0.40143	0	0.92627
8	Gombe	0.24791	0.43813	0.38306	0.65964
9	Abuja	0.36499	0.64507	0.56399	0.97119
10	Egbin-PS	0.49722	0.4982	0.11808	1
11	DELTA PS	0.52324	0.08414	0.41108	1
12	AES	0.49723	0.49822	0.1181	1
13	Okpai	0.68222	0.3284	0.5944	1
14	Calaba	0.77021	0.52559	0.70799	1
15	Aladja	0.49372	0.03866	0.37798	1.0008
16	Kano	0.28146	0.49744	0.43492	0.74893
17	SAP P/S	0.4793	0.01705	0.36212	1
18	Aja	0.49404	0.49502	0.11733	0.99362
19	Ajaokuta	0.4715	0	0.3521	1.00387
20	N Haven	0.63933	0.30084	0.55495	0.9555

Table 7: Continued

Number	Name	BUS 1	BUS 2	BUS 3	Normal
21	Alaoji	0.68826	0.37483	0.61049	0.96373
22	AFAM GS	0.77216	0.48256	0.70094	1
23	Jebba	0.17027	0.5587	0.45327	0.99946
24	JebbaGS	0.17335	0.56066	0.45565	1
25	KAINJIGS	0.24259	0.60307	0.50763	1
26	B Kebbi	0.23862	0.5932	0.49933	0.98364
27	Shiroro	0.37582	0.6642	0.58072	1
28	Kaduna	0.33955	0.6001	0.52467	-14.41

Table 8: Line flows due to 3 phase faults

				BUS 1		BUS 2		BUS 3	
From number	To number	Circuit	Xfrmr	Phase Cur A From	Phase Cur A To	Phase Cur A From	Phase Cur A To	Phase Cur A From	Phase Cur A To
1	2	1	Yes	1067.7	1028.85	981.3	1018.4	135.72	113.43
3	1	1	No	854.43	888.31	135	64.89	716.72	689.39
4	1	1	No	946.05	953.32	172.2	141.79	812.47	794.31
23	1	1	No	611.44	620.27	381.1	432.11	454.04	494.13
23	1	2	No	611.44	620.27	381.1	432.11	454.04	494.13
23	1	3	No	611.44	620.27	381.1	432.11	454.04	494.13
3	2	1	Yes	186.1	108.13	781.4	822.2	711.2	675.93
3	2	2	Yes	186.1	108.13	781.4	822.2	711.2	675.93
2	6	3	No	674.19	669.23	1078	1076.9	781.04	777.02
2	11	1	No	390.25	365.87	449.8	446.85	405.36	384.93
2	17	1	No	171.06	158.81	212.8	212.51	181.14	171.04
2	17	2	No	171.06	158.81	212.8	212.51	181.14	171.04
2	19	1	No	51.64	34.49	0	0	38.56	25.76
19	2	2	No	34.49	51.64	0	0	25.76	38.56
4	3	1	No	1005.01	978.48	120	140.75	761.93	769.18
3	7	1	No	173.33	173.55	175.6	175.87	0	0
3	7	2	No	173.33	173.55	175.6	175.87	0	0
3	10	1	Yes	1021.3	1002.48	1013	995.01	1188.31	1185.68
10	3	2	Yes	1011.96	1013.84	1004	1005.9	1188.05	1188.31
5	8	1	No	127.13	152.15	224.7	268.9	196.44	235.1
28	5	1	No	228.23	250.71	403.4	443.08	352.66	387.39
6	13	1	No	748.26	730.99	778.4	768.81	753.87	737.86
6	20	1	No	329.66	315.7	310.2	294.73	316.96	299.99
6	21	1	No	192.21	152.77	228.3	200.91	200.57	161.03
27	9	1	No	80.17	93.94	141.7	166.02	123.88	145.16
27	9	2	No	80.17	93.94	141.7	166.02	123.88	145.16
10	12	1	No	375.1	375.1	380.7	380.71	425.61	425.61
10	18	1	No	98.48	103.01	98.68	103.22	23.39	24.46
10	18	2	No	98.48	103.01	98.68	103.22	23.39	24.46
15	11	1	No	358.72	343.77	414	411.4	372.64	359.93
14	21	1	No	42.33	79.4	60.12	93.3	45.59	83.21
15	17	1	No	358.72	365.49	414	414.58	372.64	378.2
28	16	1	No	207.18	233.4	366.2	412.49	320.14	360.65
20	21	1	No	252.31	194.69	326.7	295.85	272.64	221.09
21	22	1	No	221.97	209.76	273.2	265.7	235.17	223.97
21	22	2	No	221.97	209.76	273.2	265.7	235.17	223.97
24	23	1	No	288.21	288.96	275	276.45	275.31	276.82
24	23	2	No	288.21	288.96	275	276.45	275.31	276.82
25	23	1	No	640.92	648.84	606.4	619.01	615.01	628.38
25	23	2	No	640.92	648.84	606.4	619.01	615.01	628.38
27	23	1	No	636.5	671.41	671.8	716.91	675.12	718.76
27	23	2	No	636.5	671.41	671.8	716.91	675.12	718.76
26	25	1	No	45.14	42.37	112.2	105.33	94.46	88.66
28	27	1	No	328.9	315.75	581.3	558.03	508.21	487.89
28	27	2	No	328.9	315.75	581.3	558.03	508.21	487.89

well as Fig. 7. The voltages were very high in this scenario except for buses 5,8, 16 and 28 which recorded very low values. There was no bus voltage in the network that was within the acceptable limits.

Three-Phase balanced fault: The bus voltages after the simulation are shown in Table 7 for buses 1, 2 and 3 and compared with the normal condition as well as Fig. 8. The results showed low voltages at all the buses. Only one phase voltage was recorded in this analysis since the voltages were identical for all the three phases except the phase angles. The current also went up astronomically and recorded the highest value of 1068 amperes from line 1-2 when Oshogbo was short circuited, 987 amperes from line 1 to 2 for bus 2 and 814 amperes on line 1 to 4. as shown in Table 8. The values obtained under normal condition for these lines were 168 amperes on the line 1 to 2 and 275 amperes for line 1-4 . In order to restore the system after this fault, reactive power compensation was injected into the system at locations with low voltage values at buses 5, 8, 16.

TRANSMISSION CONSTRAINTS IN THE NIGERIA TRANSMISSION NETWORK

The transmission constraints for 2004 and 2005 are grouped into transmission lines, shunt reactor and transformers as summaried in Table 9 (PHCN, 2006, 2005).

POWER OUTAGES AND VOLTAGE/FREQUENCY CONTROL POLICY IN NIGERIA

The transmission network is also characterised by frequent outages due to aging resulting in frequent conductor/jumper cut, frequent earth faults resulting from reduction in overhead clearance and refuse burning, circuit breaker problems, etc. A total of 3585 outages were recorded in 2005 out of which 65.78% were emergency outages. The outages on 330KV grid in 2005 was 529 with forced outages constituting 225 (PHCN, 2006, 2005) compared to 2004 value 277 and 2003 of 252. A summary of outages for 2003, 2004 and 2005 is shown in table 10. Voltage control policy in 2004 and 2005 was operated outside statutory limit of ±5% but instead was based on + 5% and-15% on 330KV and +10% and-15% on 132KV lines (Onohaebi and Kuale, 2007). Frequency control operated outside limit of ±1% due to insufficient generation in 2005 leading to frequency excursions below

Table 9: Summary of faults, causes and effects on the network

Line	Faults	Causes	Effect on the network
Ikorodu-Ayede-Oshogbo 132kV	Frequent Conductor/Jumper cut along entire length	Circuit was constructed in 1964 and is aging	Frequent and prolonged outages on the circuit
Akangba-Ojo 132kV circuit	Frequent Earth Fault	Reduction of overhead clearance refuse burning due proliferation of houses and stations. Industrial pollution of lines and insulators due to heavy refuse dumps and heavy industrial built up reported since 1983	Frequent forced outages on the circuits
Gombe-Maiduguru 132kV circuit	Large voltage drops of 20-40kV between Gombe and Maiduguri	Line is single circuit and is too long (310km) conductor size is also small 150mm^2	Gombe 132kV bus has to run as high as 140-145kV to enable acceptable voltage levels at Maiduguri Gombe 132kV has to be run split.
New-Haven-Oturkpo-Yander	About 20kV voltage drop between New Haven and Yander	Single line configuration using 150mm^2 and line is 330km long	New Haven 132kV bus voltage had to run high voltage
Benin-Onitsha-Alaoji-330kV	Constant tripping of Benin -Onitsha-Aladja Lines	Limited by single line contingency voltage control problems	Frequent shutdown of Afam Power Station due transmission line faults thus stressing the Afam P. S. Units Restoration of Electricity Supply prolonged due to voltage control problems. About 11 state capitals and environs experienced prolonged blackouts.
Aba-Itu 132kV line	Frequency of tripping of line	Breakdown of only one circuit breaker on the line with no provision for by-pass facilities and is limited by single line contingency	Prolonged blackout of Itu, Eket and Calabar complex serving the majority of cross River and Akwa Ibom State
Delta-Benin 132kV DC	Several spans of collapsed towers	Poor maintenance and aging	No output for Delta O. S. generation through the interbus transformer to Benin TX station on 132kV circuit
Delta/Sapele/Aladja 330kV configuration	Poor configuration leading to poor maintenance and operation of Aladja Steel switch gear by PHCN	The arrangement is defective since power flows from Sapele/ Delta PS through Aladja Delta Steel Company	Fault tracing/Clearing is very precise energy metering is difficult
Reactors Onitsha 9Rs-30MX	Reactor out of Circuit	Low resistance causes the reactor to be out of circuit	High voltages experienced at Onitsha and New Haven substations respectively. When Afam P. S. generation is separated, it took long time to synchronise the station to the grid because of high voltage difference, resulting in many areas thrown into darkness.
Oshogbo 4R1-75 MX	Reactor out of service	Faulty winding	Excessive high voltage at Oshogbo
Benin Kebbi 19R1-30MX	Reactor out of service	Burnt underground cable	High voltages at Birnin Kebbi above limits
Transformer loaded above 100% in 2004 and 2005			

Table 9: Continued

Location	Rating	Transformatio N ratio	Percentage loading (%)
Abeokuta	30MVA	132/33KVA	111
Apapa Road	30MVA	132/33KVA	111
Apapa Road	30MVA	132/33KVA	111
Akoka	15MVA	132/11KVA	109
Ejigbo	30MVA	132/33KVA	109
Ejigbo	30MVA	132/33KVA	109
Jericho	15MVA	132/33KVA	108
Otta	60MVA	132/33KVA	104
Aja	150MVA	132/33KVA	104
Akwanga	30MVA	132/33KVA	107
Kankia	7.5MVA	132/33KVA	101
Gusau	15MVA	132/33KVA	101
Hadeja	15MVA	132/33KVA	101
Benin	30MVA	132/33KVA	101

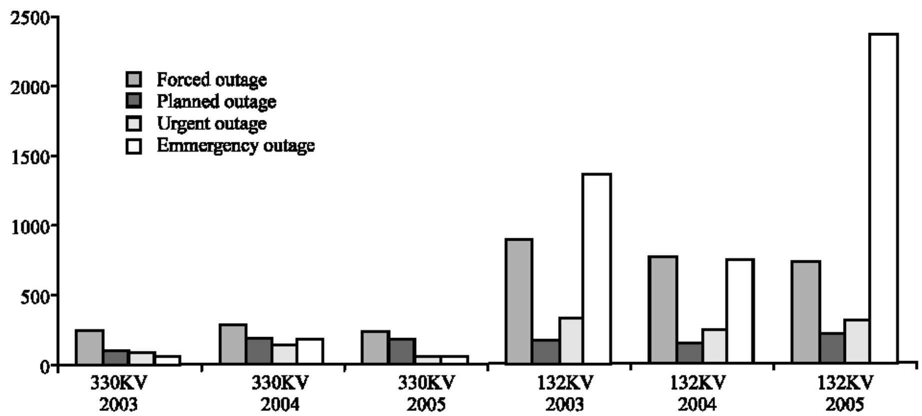

Fig. 9a: Contributions of various types of outages

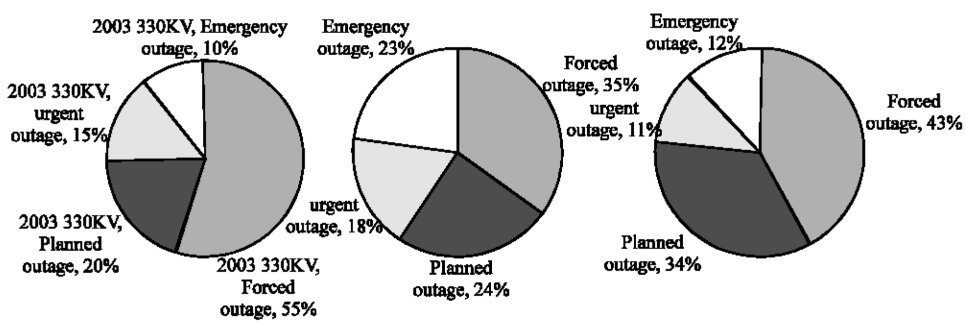

Fig. 9b: Comparison of various types of outages in the 330KV network for 2003,2004 and 2005

operating limit. Figure 9a and b showed the contributions of various types of outages in the Nigeria transmission network as reflected in Table 10.

DISCUSSION

This study revealed the following:

- The Nigerian 330KV and 132KV networks are constraints by various factors militating against effective power transmission.
- The existing network is characterised by poor maintenance and over aged leading to collapsed of several spans.
- Prolonged and frequent outages are phenomena in the transmission networks. It was observed that planned outages on the 132KV recorded the highest value of 7% while the others are either due to forced outages or emergency/urgent outages as summarised in Table 10. This suggested that the reliability of the network is very low resulting in very low efficiency and disruption in the lives of the citizenry.

Table 10: Summary of outages in Nigeria for 2003, 2004 and 2005

Year	Network	Forced outage	Planned outage	Urgent outage	Emergency outage
2003	330KV	252	90	69	48
2004	330KV	277	190	139	179
2005	330KV	225	181	59	64
2003	132KV	884	169	321	1361
2004	132KV	759	130	240	752
2005	132KV	731	200	296	2358

- Most of the transmission lines are very long and fragile leading to frequent conductor cuts. This gives rise to high voltage drops and power losses in the network. The voltages can be as low as 217 KV for a 330 KV line and 92 KV for 132 KV lines. The estimated energy losses for 2005 were 337.5 GWH (Onohaebi and Kuale, 2007).
- Some lines in networks are limited by single line contingency and small conductor sizing. Apart from the high voltage drops associated with such lines, they are subjected to constant tripping and have to run at very high voltage up to 150 KV for 132 KV line.
- High voltages are experienced in some very long lines where the reactors are out of circuits due to low resistance, winding faults and damaged cables.
- Overloading of transformer is a major phenomenon and this could have adverse effect on the power network.
- Voltage and frequency control policies by PHCN are operated outside the statutory limits. These resulted from poor transmission network and insufficient generation.
- The simulation of the various faults showed that all the bus voltages resulting from the 3 phase balanced faults were very low. The single line to ground fault recorded very high voltage at some buses, while others were within acceptable limits. The double line to ground fault recorded astronomical high voltages, while the line to line fault was similar to the normal condition.

RECOMMENDATIONS

In order to enhance good power transmission and reduce transmission constraints in Nigeria, the following should be taken into consideration:

- Identify weak areas in the network with a view to reduce the voltage drops and power losses in the network.
- Planned and routine maintenance should be carried out on the network.
- There is urgent need to replace the over aged lines and reinforce fragile ones in the network to improve the voltage stability and efficiency in the network.
- Additional circuits and loops should be introduced into the network to reduce the single line contingency constraints associated with most parts of the network.
- Good protection system taking into consideration the short circuit current in the network should be put in place to assist in fault isolation and protection of the network.
- More substations should be introduced into the network to assist in the reduction of long lines and improve the voltage profiles of the network

CONCLUSION

The various causes and effects of power faults and power transmission constraints were analysed in this paper. Outages in the network are due to aging of equipment/defects, lighting, vandalization, poor maintenance, etc. The fault analysis showed that the system needs to be properly protected to ensure safety and security of network.

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