Fault Analysis of Nigerian 330kV Power System

Ulasi, Atuchukwu John (Ph.D)
Dept of Electrical/Electronic Engineering, Anambra State University, Uli Nigeria.
johnulasi@yahoo.com

Abstract: This work involved the study and simulation of various faults, (single line-to-Ground fault L-G, line-to-line fault L-L, 3phase Balanced fault L-L-L, and Double line-to-Ground L-L-G) in the Nigeria 330kV power network system and the analysis of results. Data from Power Holding Company of Nigeria (PHCN), National Integrated Power Projects (NIPP), now Niger Delta Power Holding Company of Nigeria (NDPHCN), and Independent Power Producers (IPP) between September 2009 and December 2012 were collected and processed. The Network was then modelled in both ETAP 4.0 Transient Analysers and Power World Simulator (PWS) 8.0 Environment using Symmetrical Components equation and Newton-Raphson Power Flow algorithm. The essence of this model is to determine the time limit of transient fault, before, during, and after 3phase fault occurrences in the largest generating station (Egbin) in the network. Results obtained indicate that there were some weak bus voltages outside the statutory limits of (0.95p.u.-1.05p.u.). These include: Gombe, Jos, Kaduna, Kano, Shiroro, Abuja (Katampe), Sapele, and National Control Centre. Total load in the system was 3000MW+j000.00 MVAR and total generation was 3029.9+j3408MVAR. Power losses from the existing generating stations and transmission lines were 29.9MW-j3408MVAR from September 2009 to December2011.Total load in the system was 3496.589MW-j2869.397MVAR, and total generation was 4328.543-j335.777MVAR. Power losses from existing generating stations and transmission lines were 831.942MW - j066.000MVAR from December 2011 to December 2012.Results obtained from ETAP and PWS, showed that the most severe fault is that of 3phase balanced fault and the highest fault current is that of line-to-ground fault. The actual value of fault current is dependent on the number of generating plants actually in service at the time the fault occurs.

Key words: Simulation, fault, power, algorithm, dependent, and plant.

1. INTRODUCTION

Prior to the current reform going on in PHCN, federal government of Nigeria was responsible for policy formulation, regulation, operation and investment in the Nigeria power sector. Consequently, FGN establish the power holding company of Nigeria (PHCN- the initial holding company) and subsequently unbundled it into eighteen (18) successor companies (PHCN, 2012). The federal government owned electricity system now comprises:

1. Three hydro and seven thermal generating stations with a total installed capacity of about 6,852MW, with available capacity of 3,542MW (PHCN Record as of 31st July 2010), each entity has been incorporated as a single –asset generating company;
2. An integrated transmission grid (330kV and 132kV), owned and managed by the transmission company of Nigeria, with the responsibility of undertaking the system operation and market settlement function respectively; and
3. Eleven distribution companies (33kV and below) that undertake the wires, sales, billing collection and customer care functions within their area of geographical monopoly (PHCN, 2012). This reform is targeted at arresting poor operational and financial performance of PCHN. The current grid lacks the technical adequacy to handle (14,000MW) reform plan for the country by 2013, stated (the President, Federal Republic of Nigeria). 330kV power grid is pertinent to ascertain the performance state of the network for the scheduled load and generation. The existing network in the past one year has expanded from 9 generators to 17 generating station, 28 buses to 41 buses and 32 transmission lines to 64 lines (Omorogiuwa & Emmanuel, 2012), hence requires re-evaluation of its power evacuation capabilities as well as assessment of the impact of adding more generators and transmission facilities to this new network

1.1 Background of the Nigerian Power Sector

Power sources in the Nigerian Industry are generation from hydro, coal, oil, gas and have capacity for geothermal, solar, wind, tide and wave energy as well as combustible, renewable and waste. There are ongoing studies & research on Nuclear Power. Energy Resources for Nigeria is huge as can be seen on the table.

Table1.1: Energy Resources for Nigeria.

Resource	**Reserves / Natural Unit**
Crude Oil	35.2 billion barrels
Natural Gas	187.44trillion scf
Tar sands	30billion barrels of oil equivalent
Goal & Lignite	4billion tones
Large Hydropower	11,250MW
Small Hydropower	3,500MW
Fuel wood	13,071,464Hectares
Animal Waste	61 Million tones / year
Crop Residue	83 Million tones / year
Solar Radiation	3.5 — 7.OkWh/m2-day
Wind	2 - 4m/s at l0m height

Source: Energy Reserves for Nigeria (Sambo 2008)

1.2 Overview of Nigeria Integrated Power System and its Status as at January 18, 2010

The 330kV, Nigerian Power system structure consist of the following transmission system data, (Bada, 2012)

Nominal Voltage	330KV
Statutory Limits	313.5KV-346.5KV
Nominal frequency	50Hz
Statutory Limits	49.75Hz-50.2Hz
Peak Demand forecast	8,080MW
Generation Capability	5,317MW
Peak Generation	4,162MW
Maximum energy generated	93,224MWH

Transmission Grid January 2012 (Source: TCN) as at January 2012, the transmission Grid was made up of:
- 5,650km of 330kV Transmission Line
- 6,687km of 132 kV Transmission Line
- 62.5km of66kVTransmission Line
- 28no's 333/132kV substation (7, O44MVA)
- 1l9 no's 132/33/11Kv substation (9,852MVA)

This can only guarantee 5,000MW on 330kV and 8,000MW on 132kV.

The Nigerian Power system is one of the fastest developing power systems of the third world countries with a demand growth of 7% per annum, (The Presidency FGN, 2010).

1.3 Objectives of Study

The main objective is to perform a fault analysis of Nigerian 330kV power System. Specifically the following faults will be determined;

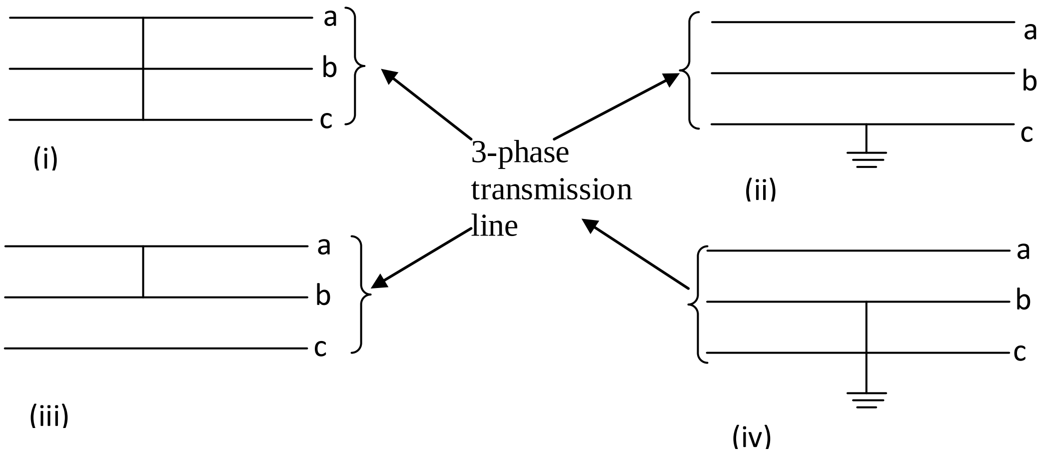

Figure 1.1: Four common types of faults

2. 1 Basic Concepts of Fault

A fault on a power system is an abnormal condition that involves an electrical failure of power system equipment operating at one primary voltage within the system.

Two types of failure can occur:

(1) Insulation failure that can result in a short-circuit fault and can occur as a result of overstressing and degrading of the insulation over time or due to sudden over voltage condition. Short circuit fault can be between phases. It may be:
   - (a) Single-line- to- ground fault
   - (b) Line –to- line fault
   - (c) Double-line-to ground fault
   - (d) 3 phase symmetrical/balanced fault

(2) Failure that results on a cessation of current flow or an open circuit fault (Nasser, 2008).

3.1 Research Methodology

This section presents the methodology of this paper:

(i) Review of Nigeria 330KV transmission grid with emphasis on fault analysis.

(ii) Steady state assessment of the network through load flow using Newton-Raphson (N-R) algorithm.

(iii) Fault analysis using, power world simulator (PWS), and ETAP analyser to compare the results.

Selection of priority areas for fault study in the 330kV network, (one major buses was selected for the fault study, Egbin G.S, because it is the largest generating station with actual generating capacity of 1100MW and peak generation of 968MW as at 24th, December 2012,it's effect on other generators and buses in the grid;

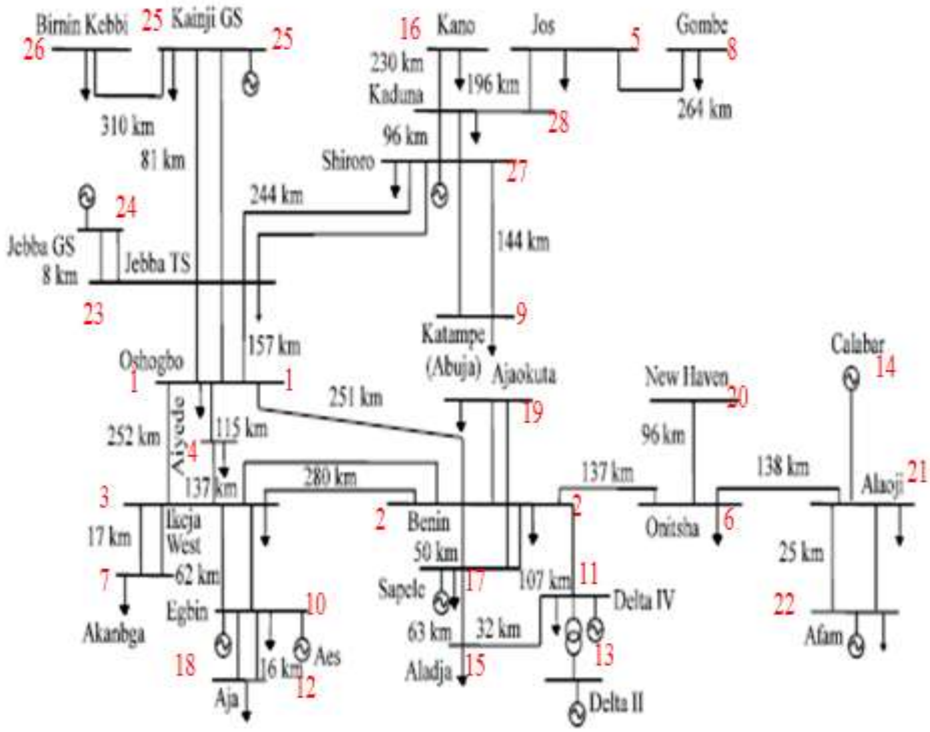

Figure 3.1 Modelled 28-buses Nigerian Power Network

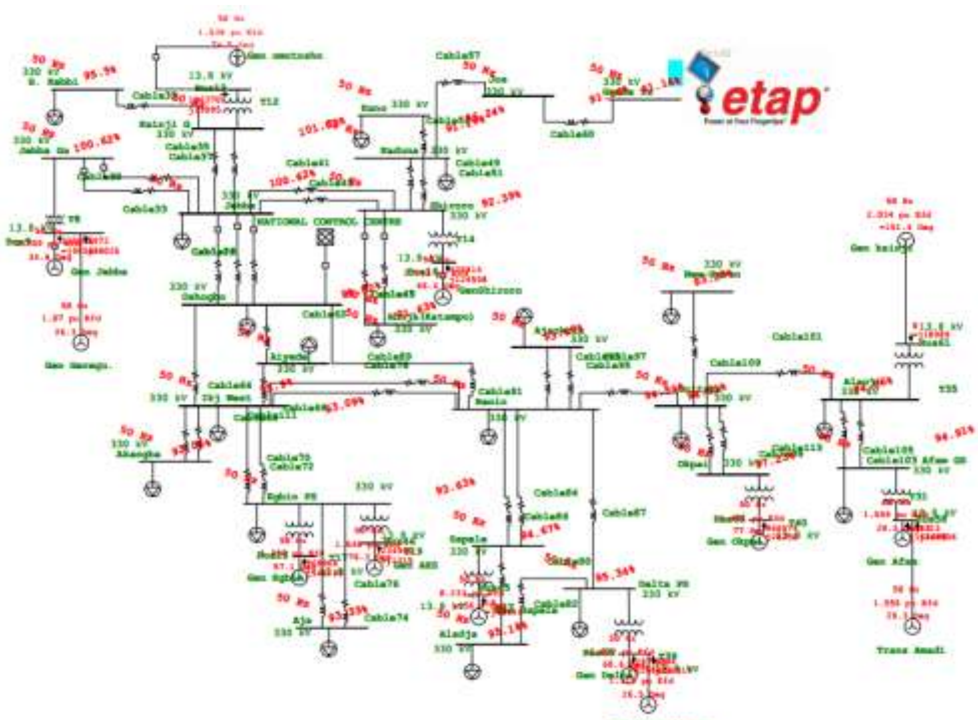

Figure 3.2: Shows the load flow modelling of the Nigeria 330KV integrated power network using Etap

4.1 Results

Table 4.1: The bus voltages at Ideal and Normal Conditions for 36 buses @ T=0

	Swing	Volt. Ctrl.	Load	Total
Number of Buses:	1	9	26	36

	XFRM2	XFRM3	React.	Line/ Cable	Imp.	TiePD	SPDT	Total
Number of Branches:	10	0	0	43	0	0	0	53

	Synch. Gen.	Synch. Motor	Ind. Mach.	Util. Syst.	Total
Number of Machines:	13	0	0	1	14

Bus Information & Nominal kV				Init. Voltage		Generation		MTR Load @T=0-		Static Load		Mvar Limits	
ID	Type	kV	Description	% Mag.	Ang.	MW	Mvar	MW	Mvar	MW	Mvar	Max.	Min.
Abuja(Katamp	Load	330.000		101.5	-1.2			141.597	87.605	94.398	58.403		
Afam GS	Load	330.000		101.5	-1.2			71.995	44.997	47.997	29.998		
Aiyede	Load	330.000		101.5	-1.2			125.970	78.069	83.980	52.046		
Aja	Load	330.000		101.5	-1.2			119.999	74.400	79.999	49.600		
Ajaokuta	Load	330.000		101.5	-1.2			43.197	26.998	28.798	17.999		
Akangba	Load	330.000		101.5	-1.2			233.376	144.633	155.584	96.422		
Aladja	Load	330.000		101.5	-1.2			47.997	24.002	31.998	16.001		
Alaoji	Load	330.000		101.5	-1.2			62.804	38.757	41.869	25.838		
B. Kebbi	Load	330.000		101.5	-1.2			53.394	33.006	35.596	22.004		
Benin	Load	330.000		100.0	0.0			81.498	50.508	54.332	33.672		
Bus9	Gen.	13.800		100.0	-1.2	345.300	0.000	0.000	0.000	0.000	0.000	-950.300	********
Bus12	Load	13.800		101.5	1.2	1067.000	0.000	0.000	0.000	0.000	0.000		
Bus16	Gen.	13.800		100.0	-1.2	430.343	0.000	0.000	0.000	0.000	0.000	121.000	0.000
Bus28	Gen.	13.800		100.0	-1.2	967.000	0.000	0.000	0.000	0.000	0.000	545.000	0.000
Bus45	Gen.	13.800		100.0	-1.2	0.000	0.000	0.000	0.000	0.000	0.000	-61.000	-61.000
Bus46	Gen.	13.800		100.0	-1.2	235.000	0.000	0.000	0.000	0.000	0.000	-2.000	-5.000
Bus58	Gen.	13.800		100.0	-1.2	12.600	0.000	0.000	0.000	0.000	0.000	329.400	0.000
Bus61	Gen.	13.800		100.0	-1.2	0.000	0.000	0.000	0.000	0.000	0.000	-19.000	-19.000
Bus65	Gen.	13.800		100.0	-1.2	304.300	0.000	0.000	0.000	0.000	0.000	709.700	0.000
Bus66	Gen.	13.800		100.0	-1.2	967.000	0.000	0.000	0.000	0.000	0.000	545.000	0.000
Delta PS	Load	330.000		101.5	-1.2			63.002	38.996	42.001	25.997		
Egbin PS	Load	330.000		100.0	0.0			104.398	64.206	69.599	42.804		
Gombe Ts	Load	330.000		106.5	1.4			0.000	0.000	0.000	0.000		
Ikj West	Load	330.000		100.0	0.0			230.391	180.007	153.594	120.005		
Jebba	Load	330.000		100.0	1.4			149.742	72.523	99.828	48.349		
Jebba Gs	Load	330.000		101.5	-1.2			0.000	0.000	0.000	0.000		
Jos	Load	330.000		100.0	0.0			0.000	0.000	0.000	0.000		
Kaduna	Load	330.000		100.0	1.4			107.990	96.605	71.993	64.403		
Kainji G	Load	330.000		100.0	0.0			0.000	0.000	0.000	0.000		
Kano	Load	330.000		100.0	0.0			75.598	48.001	50.399	32.001		
New-Haven	Load	330.000		101.5	-1.2			109.243	67.129	72.829	44.752		
Okpai	Load	330.000		101.5	-1.2			0.000	0.000	0.000	0.000		
Onitsha	Load	330.000		101.5	-1.2			87.597	46.204	58.398	30.803		
Oshogbo	SWNG	330.000		100.0	0.0			116.338	72.100	77.559	48.067		
Sapele	Load	330.000		101.5	-1.2			0.000	0.000	0.000	0.000		
Shiroro	Load	330.000		100.0	1.4			0.000	0.000	0.000	0.000		
36 Buses Total						4328.543		2026.127	1288.748	1350.751	859.165		

SUMMARY OF TOTAL GENERATION, LOADING & DEMAND

	MW	Mvar	MVA	% PF
Swing Bus(es):	-831.954	2533.620	2666.717	31.2 Leading
Generators:	4328.543	335.777	4341.547	99.7 Lagging
Total Demand:	3496.589	2869.397	4523.226	77.3 Lagging
Total Motor Load:	2026.127	1288.748	2401.262	84.4 Lagging
Total Static Load:	1166.417	738.414		
Apparent Losses:	304.045	842.235		
System Mismatch:	0.000	0.000		

Number of Iterations = 3

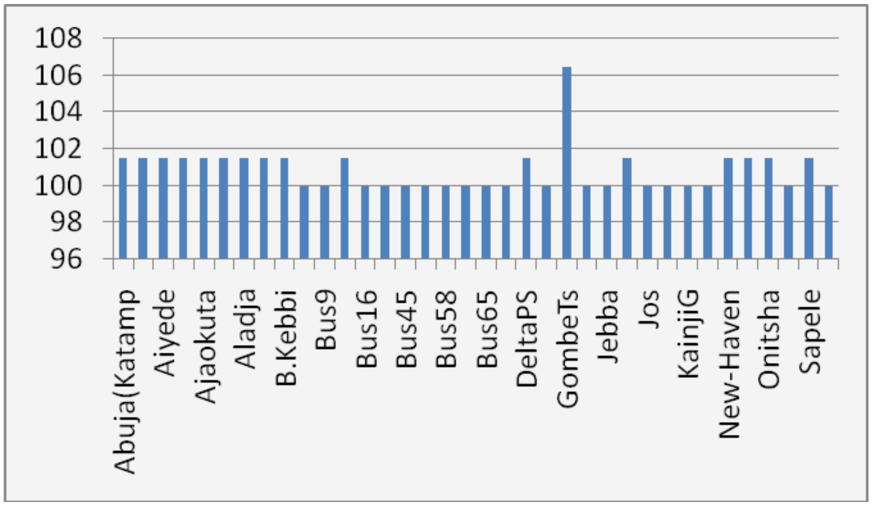

Figure 4.1: Plot of percentage Voltage profile against bus number.

From figure 4.1and table 4.1, it was observed that all the buses are within tolerable voltage limits except Gombe.

Table 4.1 and Figure 4.1 Showed that @ T = 0 the bus voltages at ideal and normal conditions, 35buses conformed to the voltage limit of (315.45KV-346.5KV) with only Gombe TS violating the voltage limit (351.45KV). Gombe TS has 2×150 MVA transformers capacity utilization in Nigeria 330KV/132KV power network and has a single circuit arrangement between it, Jos and Yola. It has a total transmission line length of 217KM between it and Yola and transmission line length of 265KM between it and Jos. (PHCN record)

Table 4.2: Initial Load Flow for three phase fault @ T=0.363

SHORT CIRCUIT ANALYSIS

3-Phase, LG, LL, & LLG
1/2 Cycle (Momentary) Fault Currents

	Swing	Gen.	Load	Total
Number of Buses:	1	9	26	36

	XFRM2	REACT.	LINE/CABLE	IMP.	TIE PD	XFRM3	TOTAL
Number of Branches:	10	0	43	0	0	0	53

	Synch. Gen.	Synch. Motor	Ind. Motor	Lump Motor	Uti-lity	Total
Number of Machines:	13	0	0	19	1	33

Bus Information (Nominal & Base kv)					Voltage		Generation		Motor Load	
ID	Type	Nom.kV	Basekv	Description	% Mag.	Ang.	MW	Mvar	MW	Mvar
Abuja(Katamp	Load	330.000	330.000		101.5	-1.2			141.597	87.605
Afam GS	Load	330.000	330.000		101.5	-1.2			71.995	44.997
Aiyede	Load	330.000	330.000		101.5	-1.2			125.970	78.069
Aja	Load	330.000	330.000		101.5	-1.2			119.999	74.400
Ajaokuta	Load	330.000	330.000		101.5	-1.2			43.197	26.998
Akangba	Load	330.000	330.000		101.5	-1.2			233.376	144.633
Aladja	Load	330.000	330.000		101.5	-1.2			47.997	24.002
Alaoji	Load	330.000	330.000		101.5	-1.2			62.804	38.757
B. Kebbi	Load	330.000	330.000		101.5	-1.2			53.394	33.006
Benin	Load	330.000	330.000		100.0	0.0			81.498	50.508
Bus9	Gen.	13.800	14.154		100.0	-30.0	345.300	0.000	0.000	0.000
Bus12	Load	13.800	13.455		101.5	1.2	1067.000	0.000	0.000	0.000
Bus16	Gen.	13.800	14.154		100.0	-30.0	430.343	0.000	0.000	0.000
Bus28	Gen.	13.800	14.154		100.0	-30.0	967.000	0.000	0.000	0.000
Bus45	Gen.	13.800	14.154		100.0	-30.0	0.000	0.000	0.000	0.000
Bus46	Gen.	13.800	14.154		100.0	-30.0	235.000	0.000	0.000	0.000
Bus58	Gen.	13.800	14.154		100.0	-30.0	12.600	0.000	0.000	0.000
Bus61	Gen.	13.800	14.801		100.0	-1.2	0.000	0.000	0.000	0.000
Bus65	Gen.	13.800	14.154		100.0	-30.0	304.300	0.000	0.000	0.000
Bus66	Gen.	13.800	14.154		100.0	-30.0	967.000	0.000	0.000	0.000
Delta PS	Load	330.000	330.000		101.5	-1.2			63.002	38.996
Egbin PS	Load	330.000	330.000		100.0	0.0			104.398	64.206
Gombe Ts	Load	330.000	330.000		106.5	1.4			0.000	0.000
Ikj west	Load	330.000	330.000		100.0	0.0			230.391	180.007
Jebba	Load	330.000	330.000		100.0	1.4			149.742	72.523
Jebba Gs	Load	330.000	330.000		101.5	-1.2			0.000	0.000
Jos	Load	330.000	330.000		100.0	0.0			0.000	0.000
Kaduna	Load	330.000	330.000		100.0	1.4			107.990	96.605
Kainji G	Load	330.000	330.000		100.0	0.0			0.000	0.000
Kano	Load	330.000	330.000		100.0	0.0			75.598	48.001
New-Haven	Load	330.000	330.000		101.5	-1.2			109.243	67.129
Okpai	Load	330.000	330.000		101.5	-1.2			0.000	0.000
Onitsha	Load	330.000	330.000		101.5	-1.2			87.597	46.204
Oshogbo	SWNG	330.000	330.000		100.0	0.0			116.338	72.100
Sapele	Load	330.000	330.000		101.5	-1.2			0.000	0.000
Shiroro	Load	330.000	330.000		100.0	1.4			0.000	0.000
36 Buses Total							4328.543		2026.127	1288.748

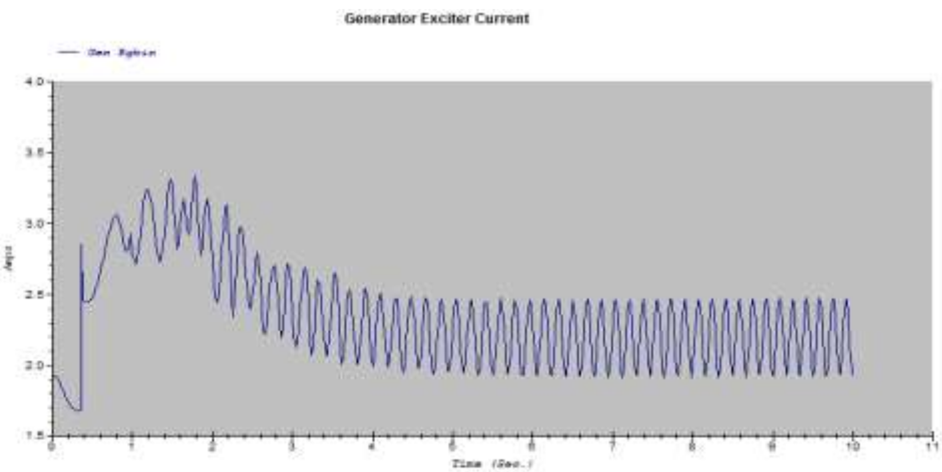

Figure 4.2 (a): Plot of Egbin Generator exciter current against time

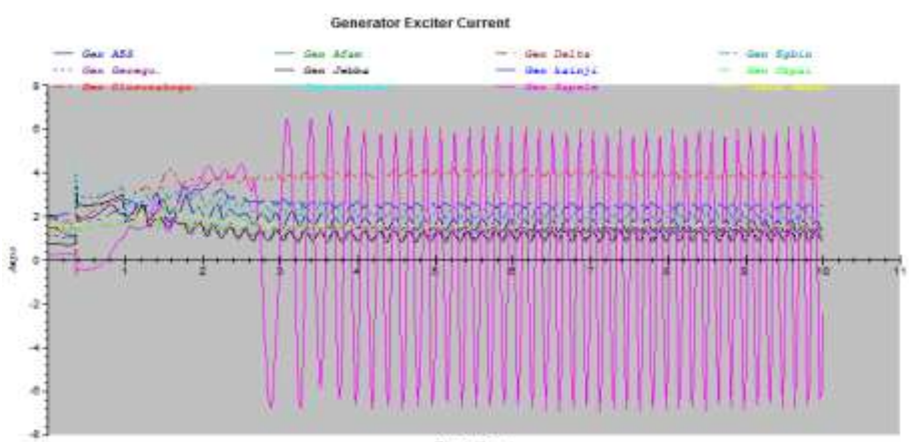

Figure 4.2 (b): Plot of Generator Exciter current against time

Figure 4.2 Shows that under 3 phase pre-fault peak value at 0.000seconds to 0.363seconds the exciter current of Egbin GS was 1.92pu, while during fault peak values at 0.3633seconds – 2.08seconds it rose up to 2.98pu but after fault condition (dynamic stability), the exciter current dropped to 1.27pu. This suggests that at fault, exciter current of the affected generator goes higher than during pre-fault and after fault. This is a reflection of what happened in other generators.

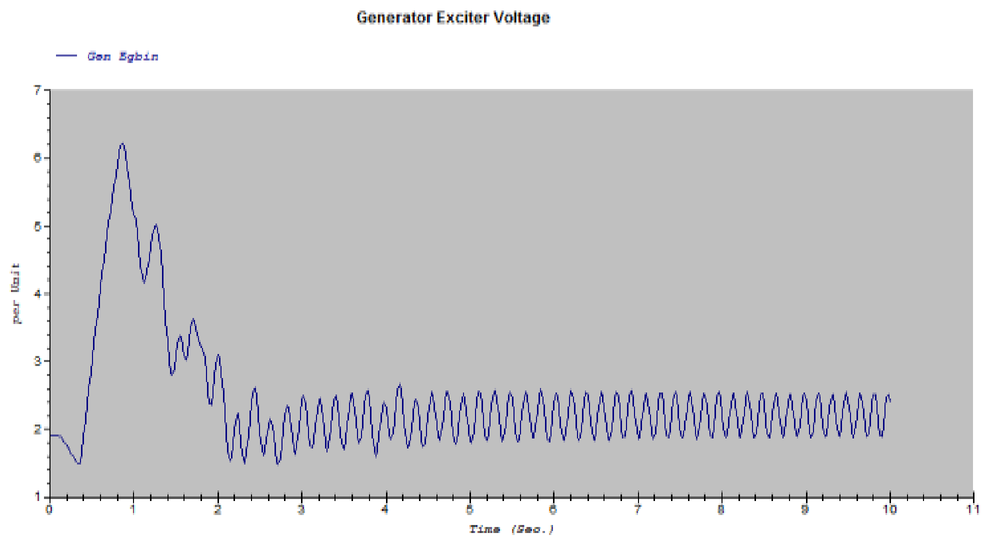

Figure 4.3 (a): Plot of Egbin Generator Exciter Voltage against time

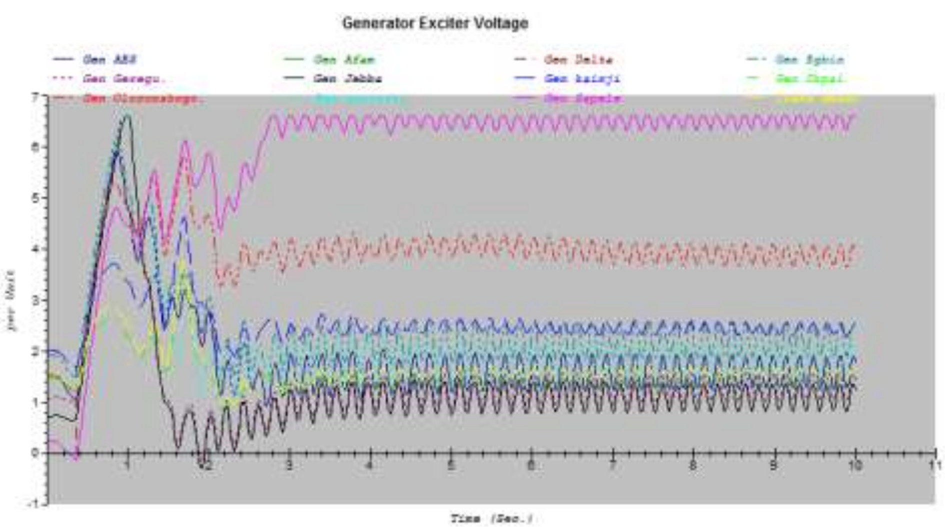

Figure 4.3 (b): Plot of Generator Exciter Voltage against time

Figure 4.3 shows that at 3 – phase pre-fault peak value on 0.000seconds to 0.363seconds, the generator exciter voltage of Egbin GS was 6.23 p.u, while during fault peak values at 0.363seconds to 2.08 seconds. It dropped to 2.16 p.u, but after fault condition (dynamic stability), the exciter voltage came – up to 5.04, a reading very close to the pre-fault record. This suggests that at fault, the exciter voltage of the affected GS drops lower than the pre-fault excitation voltage. This is also a reflection of what happened in other generators.

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LIST OF ABBREVIATIONS

FGN Federal Government of Nigeria
IPP Independent Power Project
MW Mega Watt
MVAR Mega Var
NIPP National Independent Power Project
PHCN Power Holding Company of Nigeria
G S Generating Station
L G Line-to-Ground
L L Line-to-Line
L L G Line-to –Line-to-Ground
L L L Line-to-Line-to-Line
P S Power Station
T.C.N. Transmission Company 0f Nigeria
K V Kilo Volt
NDPHCN Niger Delta Power Holding Company of Nigeria
PWS Power World Simulator
T Time
P U per unit
GDP Gross Domestic Product