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Analysis for Electrical Short Circuit Studies in Forcados Terminal SPDC, Nigeria, Using Per Unit Impedance Techniques.

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ABSTRACT
The short circuit analysis study is a research conducted for Forcados Shell Petroleum Development Company (SPDC), Nigeriapowerdistribution network. Itisnecessaryforplanning, operation, futureexpansionas fault current level increases in electrical power systems due to increase in load demand, introduction of Distributed Generations (DGs) and increase in network interconnections.Theanalysiswascarried outfor appropriate selection of protection devices such as Circuit Breaker (CB), Fuse, Superconducting Fault Current Limiter (SFCL) tosolvetheproblemoffrequentpower outagescharacterized with massive resultant current and fall in voltage and frequency.Adetailed survey wascarried outontheNetworkandthePer-unit Impedance (P.I) method was used to determine the system short circuit currentand theElectrical Transient Analyzer Program (ETAP) wasalso usedtomodelthenetworkandcarryoutsimulationtocomparetheresults.Itwasobservedthat, bothresults obtainedweresimilar.The resultant short circuit current at the downstream bus-3 is 3.328KA and the upstream bus-1 20.462KA.Theresults gottenoneachbuswill aidthe protectionengineerduring protection scheme,operationandfutureexpansionofthenetworkunderconsideration.

KEYWORDS*: Distribution Network, Per-Unit Impedance (P.I) Method, Electrical Transient Analyzer Program (ETAP), Full Load Current (FLA), Short-Circuit Current (SCC).*

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I. INTRODUCTION

The occurrence of electrical fault in power distribution network are inevitable [4], though electrical power consumption may be forecasted or projected using autoregressive approach [1], [2] but this is not sufficient for short circuit evaluation or protection scheme as power demand increases, Distribution Generation (DGs) and interconnectivity increases, hence, the fault current level increased significantly and disrupts the protection coordination, [3]. The determination of current level at different elements of the distribution system for faults occurrence at different location is known as short circuit study.

Generally, in other to analyze the fault state of electrical system the device rated current or Full Load Current (FLA), Steady State Current (SSA) or Load Flow Analysis and the Short-circuit Current (SCC) must be known [9]. Basically, faults are either balance (symmetrical) or unbalance (unsymmetrical). C. L Fortescue in 1918 segregated asymmetrical three phase voltage and current entities into three set of symmetrical component[6], [8]. 15% of all transmission fault are line-to-line fault (L-L), 10% faults are L-L-G while 5% to three lines shunt (L-L-L) together [11] or three lines to ground (L-L-L-G) [13]. And unbalanced or unsymmetrical faults i.e fault involving 1-phase or 2-phase (L-L, L-L-G or L-G) are more predominant in power distribution system [12].The symmetrical fault which is the huge and very destructive in power network shall be determined with the aid of Per-unit Impedance (P.I) and Electrical Transient Analyzer Program (ETAP) considerably.

1.1 The Aim of this Research Work

The aim of this research work is to evaluate symmetrical fault current level at different locations of Forcados Power Distribution Network using per unit impedance method and ETAP simulation.

1.2 Objective of this Research Work

- Obtain data from field survey.
- Determine full load current (FLA) of associated devices in the distribution system.
- Determine per unit impedance to common base (100MVA Base).
- Determine per unit impedance up to the point of the fault.
- Determine fault level (Fault MVA) and analyzed short circuit current Isc in the distribution system.
- To estimate fault current level for protection scheme and basis for selection of electrical protective devices such as fuses, CBs etc.

II. LITERATURE REVIEW

Loadflowanalysisformsanimportantpre-requisiteforpowersystemstudies.The short circuit analysis is the analysis of the steady state solution of linear network with balance three phase excitation. It is consider very important for equipment selection as to assure fault clearance time of equipment in case of short circuit. Hand calculation has been adopted by many researchers using basic parameters in terms of which all system quantities are defined to determine fault location [14]. The P.I approach has been employed to simplify the study of short circuit current at different locations [15] but this method is complicated for larger power network. However, this research used the P.I method with the aid ofNEPSI (Northeast Power System Inc.) per-unit and base impedance calculator [16]to calculate and simplifies per-unit variables used in per-unit analysis. The per-unit value is the ratio of a quantity's real value to its base value in general (Per unit value is actual value divided be base value).

The manufacturer specifies the impedance of the device in percent. The percent value is obtained by multiplying the per-unit value by 100: Z% = Zp.u x 100%. The phrase "own base" means that the base voltage is the rated voltage of the equipment, and the base power is the rated apparent power of the equipment (in VA) which is express as:

$$V_{p.u} = \frac{V_{actual}}{V_{base}}; I_{p.u} = \frac{I_{actual}}{I_{base}}; S_{p.u} = \frac{S_{actual}}{S_{base}}; Z_{p.u} = \frac{Z_{actual}}{Z_{base}} \tag{1a}$$

$$I_{base} = \frac{S_{base}}{V_{base}}; \left(\text{Re } call \;\; S = IV\right) Z_{base} = \frac{V_{base}}{I_{base}} = \frac{V^{2}_{base}}{S_{base}}; \left(ZI = V\right) \tag{1b}$$

The above equations are for single phase system but our area of interest shall be that of 3 phase power system.
From Ohm's law V = IZ
Let's assume definitions of some quantities;
$Z, X, R =$ Actual Impedance, reactance and resistance in ohms:

$$Z\% = \frac{I_{FLA}\; x\; Z}{V_{ph}}\; x\; 100, \text{ Similar with X\% and R\%.} \tag{2}$$

III. MATERIALS AND METHOD

3.1 Materials

The materials used for this research work is detailed; single line Diagram (SLD); % impedance of per unit impedance data; ETAP software. The ETAP software shall be used for evaluation/comparison.

3.2 Single line diagram (SLD) of 11/33kv Distribution System

The SLD shows the main connections and arrangements of the system components such as alternators, power transformers, transmission lines, and loads etc.

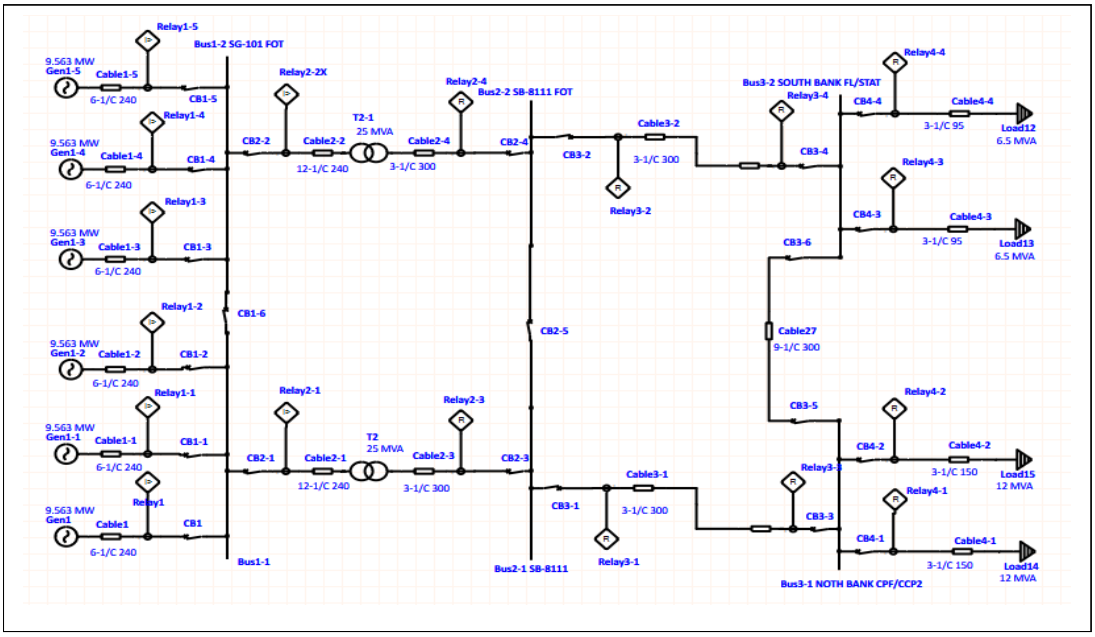


Figure 1: SLD of 11/33kv Power Distribution Network (Forcados)

3.3 Equipment Specification and Values

The % impedance of system equipment, Full Load Current (FLA), Short Circuit Current (I_{SC}) of devices are useful in fault analysis as shown in the Table 1. With the data in Table 1 the load flow analysis is conducted with ETAP as shown in Figure 2.

Table 1: Equipment Specification and Values in FOT

S/No	Parameter/System	% Z	FLA (I_R) (A)	SCC (I_{SC}) (KA)
1	GT(6No.s): 11KV, 11.25MVA, 50Hz	19	590.5	3.11
2	TR (2No.s): 11/33KV, 25MVA, 50Hz	10	437.4	4.37
3	Line: 33KV	9.6921	437.4	4.51
4	Load1 (2No.s): 33KV, 6.5MVA	6.5	113.7	1.75
5	Load2 (2No.s): 33KV, 12MVA	6.5	209.9	3.23

The Full Load Current (FLA (I_R) (A)) column is calculated with equation (3) while the Short Circuits(SCC (I_{SC}) (KA)) column isdetermined with simple mathematical expression as given in equations (4). The data in the above table are used for the simulation of load flow analysis as show in Figure 2 and short circuit analysis with Etap simulation as shown in Figure 5.

$$I_{FLA} = \frac{MVA}{\sqrt{3}\ X\ KV} \quad (3)$$

$$I_{SC} = \frac{I_{FLA}}{\%Z} \quad (4)$$

Where:
MVA: Rated Power
KV: Line voltage
%Z: Percentage Impedance
I_{FLA}: Rated Current or Full Load Current
I_{SC}: Short Circuit Current

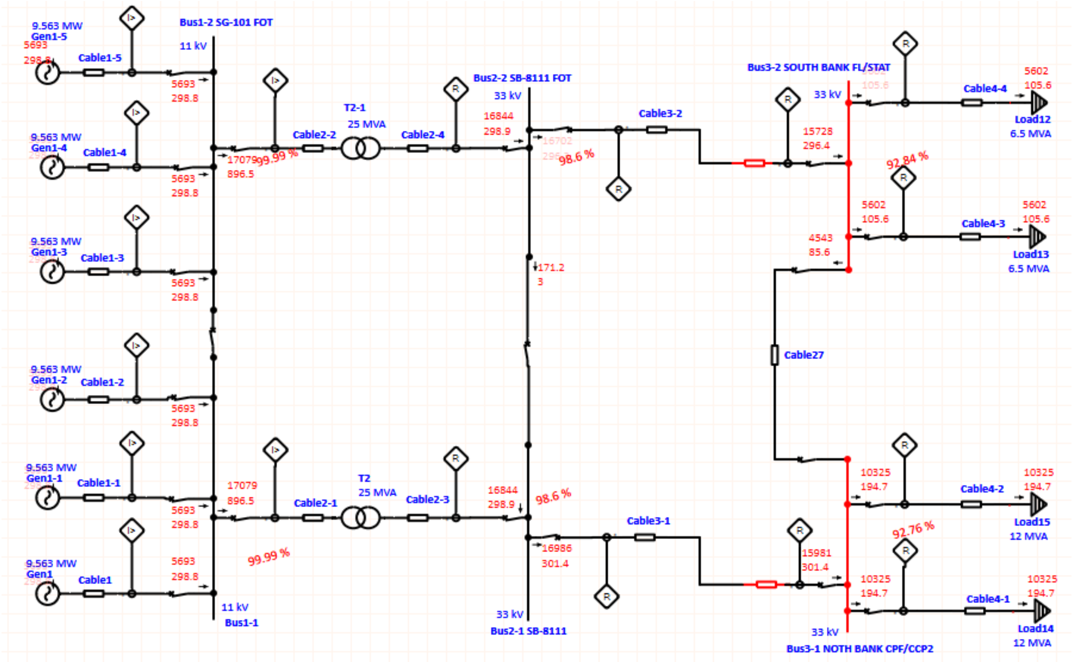


Figure 2: Steady State or Load Flow Analysis (LFA) of 11/33kv Power Distribution Network (Forcados)

3.4 Application of Impedance Method and Determination of Fault MVA and Fault Current.

The impedance technique enable the formation of impedance diagram from the SLD (Figure 1), this distribution system can sectioned or zone for easy determination of per unit impedance up to the point of fault; the per unit equation for this research is given below:

$$Z_{P.U} = \frac{Z}{Z_b} = \frac{Z}{\frac{(KV)_b{}^2}{(MVA)_b}} = \frac{Z(MVA)_b}{(KV)_b{}^2} \quad (5)$$

Base conversion expression is as follows:

$$\frac{(Z_{P.U})_o}{(Z_{P.U})_n} = \frac{(MVA)_o}{(MVA)_n} X \frac{(KV)_n{}^2}{(KV)_o{}^2} \quad (6)$$

Where:

$(MVA)_o$: Existing or old base rated power
$(KV)_o$: Existing or old line voltage
$(Z_{P.U})_o$: Existing or old per unit impedance
$(MVA)_n$: Converted or new base rated power
$(KV)_n$: Converted or new base line voltage
$(Z_{P.U})_n$: Converted or new per unit impedance

Assume Base MVA for this research is 100MVA. The fault MVA is directly proportional to the base MVA and inversely proportional to per unit impedance up to the point of faults and this can be expressed as follows:

$$Fault\ MVA = \frac{Base\ MVA}{Per\ unit\ impedance\ upto\ point\ of\ fault} = \frac{MVA_{base}}{Z_{p.uT}} \quad (7)$$

$$Fault\ current\ (I_F \text{or} I_{SC}) = \frac{Fault\ MVAx(10)^3}{\sqrt{3}xKV} = \frac{MVA_F}{\sqrt{3}xKV}x10^3 \quad (8)$$

Using the system data from Table 1,the new per unit impedance of the system can be obtained as follows:

1. Reference Bus 1-1 and Bus 1-2;

$\frac{(0.19)_o}{(Z_{P.U})_n} = \frac{(11.25)_o}{(100)_n} X \frac{(11)_n{}^2}{(11)_o{}^2}$, (Zp.u)g.eq= 1.688.

For synchronization of two generators is 1.688/2, for three generator is 1.688/3 and so on.

2. Reference Bus 2-1 and B 2-2;

$\frac{(0.10)_o}{(Z_{P.U})_n} = \frac{(25)_o}{(100)_n} X \frac{(33)_n{}^2}{(33)_o{}^2}$, (Zp.u)tr.eq= 0.4.

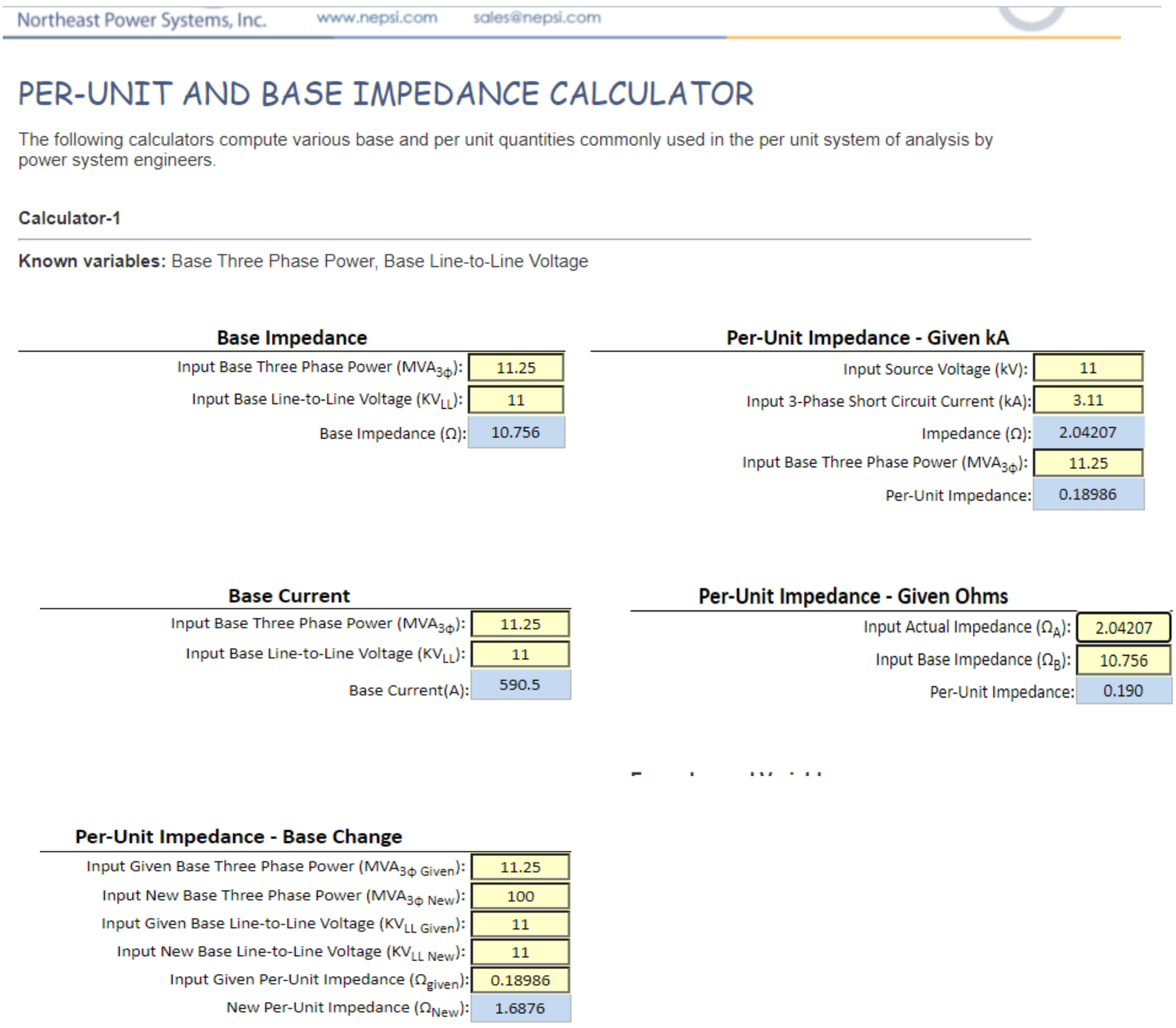
For paralleling of two transformer, (Zp.u)tr.eq is 0.4/2. Similarly, the transmission is determined using equation (5): $(\mathrm{Zp.u})\mathrm{tx.} = \frac{0.96921 \, x \, 100}{33^2} = 0.089$

This process is carried out for all devices and lines to achieve the respective per-unit impedance up to the required fault point as summarized in Table 2.Also, this is best achieved by inputting the above data in Table 1 into NEPSI software as shown in Table 3 to obtain similar values of Table 2.

TABLE 2: P.I Summary of Fault Level at Bus 3 (downstream) as generators are synchronized.

No of GEN	(Zp.u)g.eq	(Zp.u)tr.eq	(Zp.u)tx.eq	$Z_{p.uT}$	FMVA/33KV	I(F)KA
1	1.688	0.4	0.089	2.177	45.943	0.804
2	0.844	0.2	0.0445	1.088	91.886	1.608
3	0.563	0.2	0.0445	0.807	123.911	2.168
4	0.422	0.2	0.0445	0.666	150.060	2.625
5	0.338	0.2	0.0445	0.582	171.815	3.006
6	0.281	0.2	0.0445	0.526	190.198	3.328

Table 3: NEPSI Determination of P.I, FLA, ISC…



Northeast Power Systems, Inc. www.nepsi.com sales@nepsi.com

PER-UNIT AND BASE IMPEDANCE CALCULATOR

The following calculators compute various base and per unit quantities commonly used in the per unit system of analysis by power system engineers.

Calculator-1

Known variables: Base Three Phase Power, Base Line-to-Line Voltage

Base Impedance

Input Base Three Phase Power ($MVA_{3\phi}$):	11.25
Input Base Line-to-Line Voltage (KV_{LL}):	11
Base Impedance (Ω):	10.756

Per-Unit Impedance - Given kA

Input Source Voltage (kV):	11
Input 3-Phase Short Circuit Current (kA):	3.11
Impedance (Ω):	2.04207
Input Base Three Phase Power ($MVA_{3\phi}$):	11.25
Per-Unit Impedance:	0.18986

Base Current

Input Base Three Phase Power ($MVA_{3\phi}$):	11.25
Input Base Line-to-Line Voltage (KV_{LL}):	11
Base Current(A):	590.5

Per-Unit Impedance - Given Ohms

Input Actual Impedance (Ω_A):	2.04207
Input Base Impedance (Ω_B):	10.756
Per-Unit Impedance:	0.190

Per-Unit Impedance - Base Change

Input Given Base Three Phase Power ($MVA_{3\phi \text{ Given}}$):	11.25
Input New Base Three Phase Power ($MVA_{3\phi \text{ New}}$):	100
Input Given Base Line-to-Line Voltage ($KV_{LL \text{ Given}}$):	11
Input New Base Line-to-Line Voltage ($KV_{LL \text{ New}}$):	11
Input Given Per-Unit Impedance (Ω_{given}):	0.18986
New Per-Unit Impedance (Ω_{New}):	1.6876

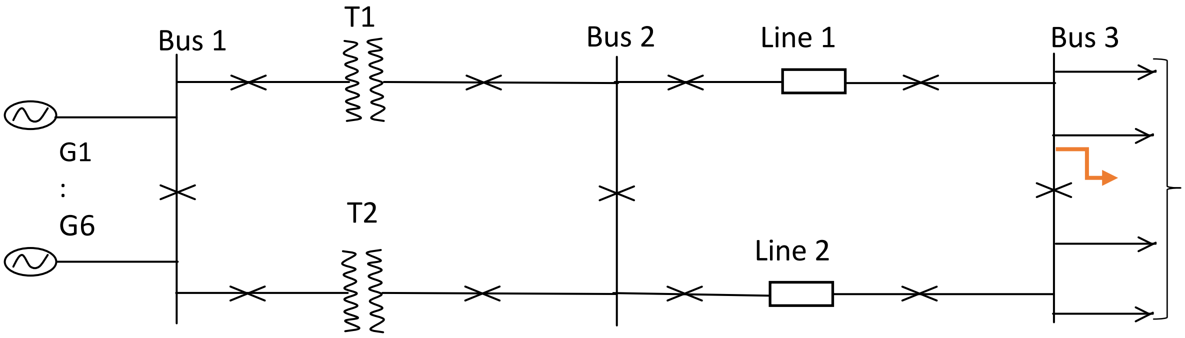


Figure 3: SLD to Estimate Fault Level at Bus 3

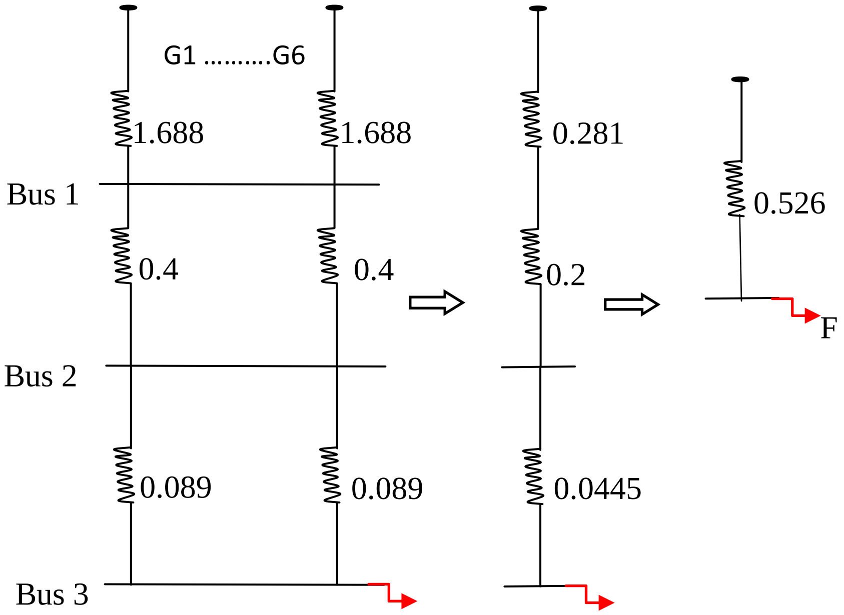
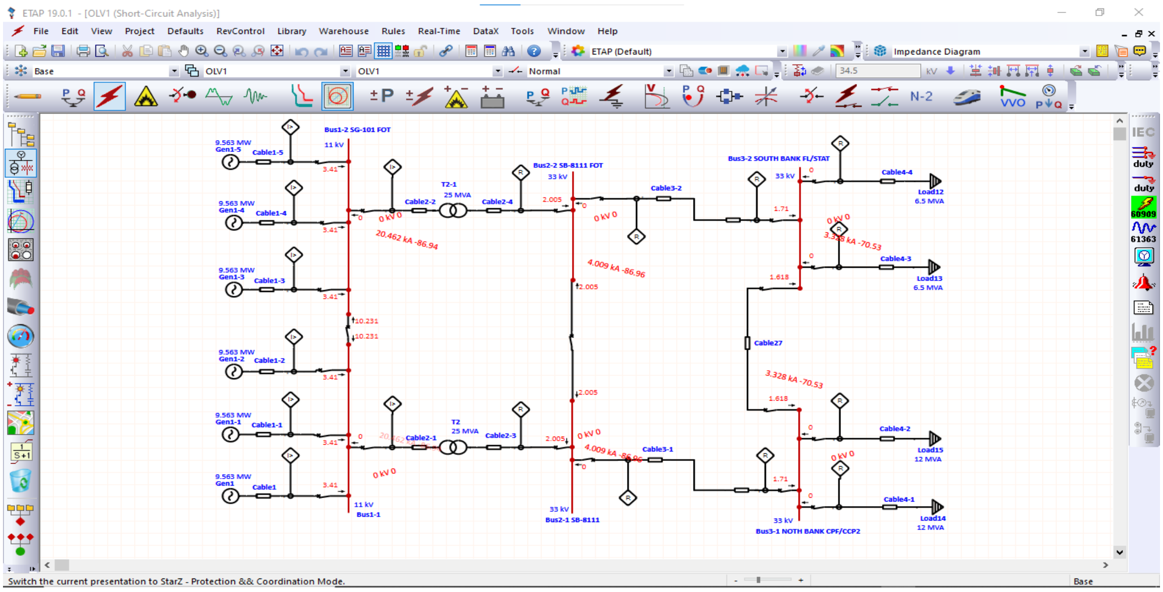


Figure 4: Per Unit Impedance Diagram of Figure. 3



Switch the current presentation to StarZ - Protection && Coordination Mode.

Figure 5: Short Circuit Analysis with Etap of 11/33kv Power Distribution Network (Forcados)

IV. RESULTS AND DISCUSSION

4.1 Results

The results gotten are shown below using Per Unit Impedance (P.I) techniques and Electrical Transient Analyzer Program(ETAP) software. The Short-Circuit Summary Report (Table 5) and Sequence Impedance Summary Report (Table 6) are shown below.

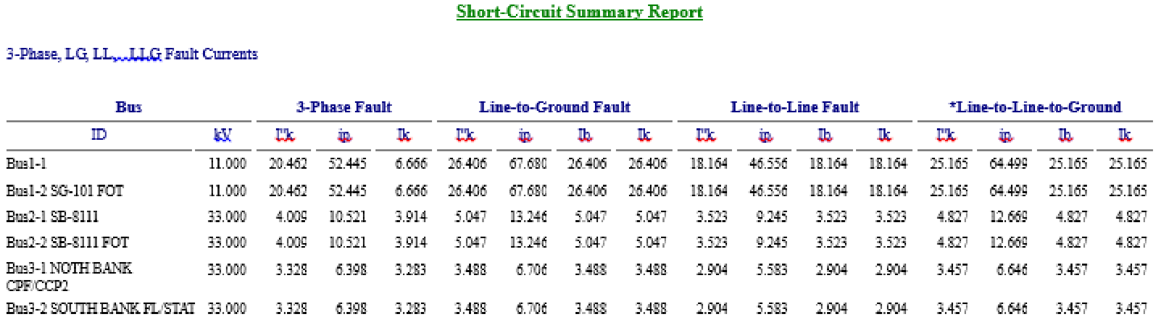
Impedance Summary Report of the 11/33KV Distribution network considering SPDC Forcados Terminal, from the application of the above mentioned methods and simulation of the power distribution system as follows:

i. Per Unit Impedance (P.I) Techniques: As the system is synchronized from generator number 1 to generator number 6 the fault level increases during system short circuit state. (See Table 3 and Table 4). Thus, for synchronizing the six generators the SCC using P.I is given below:

Bus (3-1) = Bus (3-2) = 3.328KA
Bus (2-1) = Bus (2-2) = 4.009KA
Bus (1-1) = Bus (1-2) = 20.462KA

ii. The ETAP Summary Report shown below:

TABLE 5: P.I Short-Circuit Summary at Various Buses

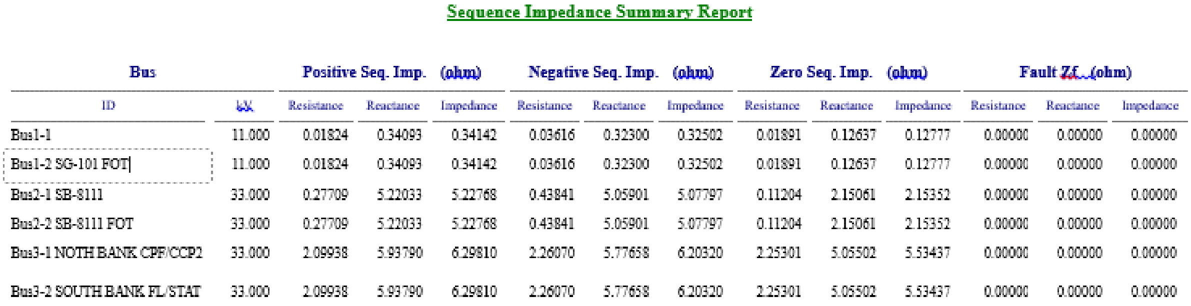


Short-Circuit Summary Report

3-Phase, LG, LL, LLG Fault Currents

Bus		3-Phase Fault			Line-to-Ground Fault				Line-to-Line Fault				*Line-to-Line-to-Ground			
ID	kV	I"k	ip	Ik	I"k	ip	Ib	Ik	I"k	ip	Ib	Ik	I"k	ip	Ib	Ik
Bus1-1	11.000	20.462	52.445	6.666	26.406	67.680	26.406	26.406	18.164	46.556	18.164	18.164	25.165	64.499	25.165	25.165
Bus1-2 SG-101 FOT	11.000	20.462	52.445	6.666	26.406	67.680	26.406	26.406	18.164	46.556	18.164	18.164	25.165	64.499	25.165	25.165
Bus2-1 SB-8111	33.000	4.009	10.521	3.914	5.047	13.246	5.047	5.047	3.523	9.245	3.523	3.523	4.827	12.669	4.827	4.827
Bus2-2 SB-8111 FOT	33.000	4.009	10.521	3.914	5.047	13.246	5.047	5.047	3.523	9.245	3.523	3.523	4.827	12.669	4.827	4.827
Bus3-1 NOTH BANK CPF/CCP2	33.000	3.328	6.398	3.283	3.488	6.706	3.488	3.488	2.904	5.583	2.904	2.904	3.457	6.646	3.457	3.457
Bus3-2 SOUTH BANK FL/STAT	33.000	3.328	6.398	3.283	3.488	6.706	3.488	3.488	2.904	5.583	2.904	2.904	3.457	6.646	3.457	3.457

TABLE 6: P.I Sequence Impedance Summary at Various Buses



Sequence Impedance Summary Report

Bus		Positive Seq. Imp. (ohm)			Negative Seq. Imp. (ohm)			Zero Seq. Imp. (ohm)			Fault Zf (ohm)		
ID	kV	Resistance	Reactance	Impedance	Resistance	Reactance	Impedance	Resistance	Reactance	Impedance	Resistance	Reactance	Impedance
Bus1-1	11.000	0.01824	0.34093	0.34142	0.03616	0.32300	0.32502	0.01891	0.12637	0.12777	0.00000	0.00000	0.00000
Bus1-2 SG-101 FOT	11.000	0.01824	0.34093	0.34142	0.03616	0.32300	0.32502	0.01891	0.12637	0.12777	0.00000	0.00000	0.00000
Bus2-1 SB-8111	33.000	0.27709	5.22033	5.22768	0.43841	5.05901	5.07797	0.11204	2.15061	2.15352	0.00000	0.00000	0.00000
Bus2-2 SB-8111 FOT	33.000	0.27709	5.22033	5.22768	0.43841	5.05901	5.07797	0.11204	2.15061	2.15352	0.00000	0.00000	0.00000
Bus3-1 NOTH BANK CPF/CCP2	33.000	2.09938	5.93790	6.29810	2.26070	5.77658	6.20320	2.25301	5.05502	5.53437	0.00000	0.00000	0.00000
Bus3-2 SOUTH BANK FL/STAT	33.000	2.09938	5.93790	6.29810	2.26070	5.77658	6.20320	2.25301	5.05502	5.53437	0.00000	0.00000	0.00000

V. CONCLUSION AND RECOMMENDATIONS

5.1Conclusion

The comparison of hand calculation using P.I and simulation using ETAP was achieved, showingthe fault current at the downstreamand upstream. The short-circuit analysis of this power distributionnetwork has clearly shown areas of modification. From the P.I calculation and the simulation results shown that the fault level at the upstream is relatively high for more than three generators in synchronism. However, the introduction of limiter between the affected buses (bus 1-1 and bus 1-2) will improved the voltage profile. Hence, the installed bus coupler CB (3500Amps) and the entire system components may not require replacement if and only ifa limiter is in the system (proposed). The use of P.I analysis for large power distribution network is complicated and time consuming but with the aid of NEPSI and ETAP software's are easier and faster. The application of ETAP software aids the SCCanalysis very accurately and proactive with less memory requirement.

5.2 Recommendation.

- I recommend that system short circuit current analysis studies should be carried out during planning stage of a power network.
- Power station should undergo acceptance test, installation test, maintenance or functional test and repair tests before pre-commissioning and commissioning.
- Routine test and system performance should be evaluated in every five years to ascertain load growth.
- 100% sufficient redundancy should be provided depending on the criticality of the electrical power system network.
- The power distribution network should incorporate limiter such as Superconducting Fault Limiter (SFCL) at the upstream to minimize fault level when the system synchronism is above three generators.

REFERENCES

[1]. Sen P., Roy M., Pal P., (2016). Application of ARIMA for forecasting energy consumption and GHG emission: A case study of an Indian pig iron manufacturing organization, Energy, 2016, 116, 10311038 http://dx.doi.org/10.1016/j.energy.2016.10.068 Search in Google Scholar

[2]. Zhang F., Deb C., Lee S. and oth, (2016). Time series forecasting for building energy consumption using weighted Support Vector Regression with differential evolution optimization technique, Energy and Buildings, 2016, 126, 94–103 http://dx.doi.org/10.1016/j.enbuild.2016.05.028 Search in Google Scholar

[3]. Idoniboyeobu D C, Braide S.L., Igbogidi O.N., (2018). Improved Relay Coordination In Port Harcourt Distribution Network Case Study Of RSU 2 X 15MVA, 33/11kv Injection Substation American Journal of Engineering Research (AJER) 7,(7), 43-56

[4]. Jun Zhu. "Analysis Of Transmission System Faults the Phase Domain", Texas A&M University. Master Thesis, 2004.

[5]. C.L. Wadhwa, "Electrical Power Systems", pp 306, New Age International, 2006

[6]. D. C. Yu, D. Chen, S. Ramasamy and D. G. Flinn, "A Windows Based Graphical Package for Symmetrical Components Analysis", IEEE Transactions on Power Systems, Vol. 10, No. 4, pp 1742-1749, November 1995.

[7]. http://helios.acomp.usf.edu/~fehr/carson.pdf

[8]. Norliana B. Salimun. "Phase Coordinates In Faulted Power System Analysis", UniversitiTeknologi Malaysia. Master Thesis, 2010.

[9]. Paul M. Anderson, "Analysis of Faulted Power Systems", The Institute of Electrical and Electronics Engineers, Inc., 1995.

[10]. T.K Nagsarkar and M.S Sukhija, "Power System Analysis", New York Oxford University Press, pp.14-25, 2005

[11]. HadiSaadat. Power System Analysis. Milwaukee Scholl of Engineering. WBC McGraw-Hill.

[12]. Ault, G.W. (2003). Strategies Analysis Framework for Evaluating Distribution Generation and Utility Strategies. Institute of Electrical and Electronics Engineers Proceeding Generation, Transmission and Distribution, 150(4), 475 – 481.

[13]. Dalstein, T. &Kulicke, B. (1995). Neural Network Approach to Fault Classifications for High–Speed Protective Relaying. Institute of Electrical and Electronics Engineers Proceeding Transactions on Power Delivery, 51(4), 1002- 1009.

[14]. Kezunovic, M. (2011). Smart fault location for smart grids. IEEE Transactions on Smart Grid, 2, 11–22.

[15]. Zimmerman, K., & Costello, D. (2005). Impedance-based fault location experience. In 58th annual conference for protective relay engineers, 2005 (211–226).

[16]. http://nepsi.com/resources/calculators/per-unit-impedance-calculator.htm

Idoniboyeobu, D.C. "Analysis for Electrical Short Circuit Studies in Forcados Terminal SPDC, Nigeria, Using Per Unit Impedance Techniques."*American Journal of Engineering Research (AJER)*, vol. 10(10), 2021, pp. 47-54.