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Fault Analysis of Mgbuoba/Ada George Area Electricity Distribution Networks

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ABSTRACT: This study presents the application of symmetrical components techniques with the integration of MATLAB/Simulink tool to determine different classes of faults conditions. Transient analyzer software tool (Etap version16.0) was used to model the existing supply chain to the study case under consideration to access system violations. The study critically examined the existing bus mismatches in the network and the effect of bus violation in Bus-6 which was about 22.2% deviation from normal operating condition which evidently presents 77.8pu. When the three-phase faults are created on the network under investigation, irregular–tripping sequence was observed and the magnitude of faults currents becomes more transient in nature with fault clearing time of 0.5sec – 0.87sec the same application was created at different zones on the network where the tripping sequence of the relay to the circuit breaker co-ordination were monitored with respect to time of discrimination of fault occurrence that leads to power outages in most time in the study area (Mgbuoba/NTA Road).

KEY WORDS: Symmetrical Faults, Asymmetrical Faults, Electrical Power System, Feeder, Impedance Matrix Method.

I. INTRODUCTION

Electrical power system entails generation, transmission and distribution. Large powers are transmitted from generating stations through conductors to distribution networks where they can be made available to consumers. Electrical power system should be stable, reliable, efficient, safe and should be of minimal cost for distribution or sale to consumers. The essence of electrical power is to be sold to the utility consumer. The electricity industry in Nigeria has grown more complex from a number of relatively small isolated power stations in the early 1950s to an integrated power supply system which the National Electricity Power Authority (NEPA) now referred to as Power Holding Company of Nigeria (PHCN) runs today [1].

Electrical faults could be symmetrical or asymmetrical. Electrical faults can be due to lightning strikes on conductor lines and substation equipment, trees falling on power lines, equipment failures, human errors and most times sabotage. Faults could lead to damage of equipment in the system due to overheating which in turn affect the stability of the system in most cases leading to shut down of the entire system. Faults have serious consequences. Therefore, understanding the causes of power failure will enable one take steps to prevent its occurrence. A report from an international journal on fault analysis in power systems by Mark & Sastry [2], asserted that when faults (short circuit) occurs at some points in the network, the normal operating conditions of the system is upset; if the fault is persistent, severe loss of load, property damage due to fire or explosion, and steep economic losses can arise as undesirable consequences.

II. LITERATURE REVIEW

In power system, a fault is a defect in the circuit that leads to current diverting from its intended path. The nature of faults implies any abnormal condition which causes a reduction in the basic insulation strength between phase conductors or between phase conductor and earth or any earthed screen surrounding the conductor. This reduction in insulation strength is not considered as a fault until it creates some effects on the system such as excessive current, reduction of impedance between conductors or between conductors and earth to a value below that of the lowest load impedance which is normal to the circuit [3]. So it is necessary to determine the types of faults and locations on the

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transmission line and clear such faults as soon as possible in order not to cause some damages. A flashover, lightning strikes to birds, winds, snow and ice load lead to short circuit[4].

When a fault is caused by an unbalance in the line impedance and does not involve the ground, or any type of interconnection between phase conductors it is known as a series fault. On the other hand, when the fault occurs and there is an inter-connection between phase conductors or between conductor(s) and ground and/or neutral it is known as a shunt fault. Statistically, series faults do not occur as often as shunt faults does [5].In a three phase system according to Gupta [6],short circuit faults can be classified as asymmetrical faults, single phase to ground fault, phase to phase fault, two phase to ground fault, phase to phase and third phase to ground, symmetrical faults, all three phase to ground fault, and all three phase short circuited fault respectively.Symmetrical fault is a fault where all the phases are similar. Examples of symmetrical fault are; when a line which has been made safe for maintenance by clamping all the three phases to earth is accidentally made alive or when due to slow fault clearance, an earth fault spreads across to the other two phases or when a mechanical excavation cuts quickly through a whole cable [6].This fault is very important as it results in an easy calculation and generally a pessimistic answer.

According to Lucas[7],the assumptions usually made in fault analysis of a three phase transmission or distribution system include all sources are balanced and equal in magnitude and phases, sources represented by the Thevenin's voltage prior to fault at the fault point, large systems may be represented by an infinite bus-bar, transformers are on normal tap positions, resistances are negligible compared to reactance, transmission lines are assumed fully transposed an all three phases have same reactance, load currents are negligible compared to fault currents, and line charging currents can be completely neglected. The above assumptions are usually considered when carrying out fault analysis on three phase system.

III. MATERIALS AND METHOD

The materials used in carrying out this work include the single line diagram of the study case (NTA Mgbuoba by Ada George), conductor size (cross-sectional area, aluminum conductor), distribution parameters bus data with network configuration, application of simulation soft-ware (Electrical – Transient analyzer Etap–12.6), the operating voltages levels, and compensating device for system improvement.

The analysis of symmetrical fault condition was achieved using impedance matrix method which can be represented using three independent symmetrical components techniques which differ in the phase-sequence. By definition, a three-phase fault is a symmetrical fault. Therefore, $I_{a0} = 0$ and $I_{a2} = 0$

$$I_{a0} = \frac{1.0<0^0}{Z_1+Z_f} \qquad (1)$$

If the fault impedance Z_f is zero then, $I_{a2} = \frac{1.0<0^0}{Z_1}$ (2)

$$\begin{bmatrix} I_{af} \\ I_{bf} \\ I_{cf} \end{bmatrix} = \begin{bmatrix} 1 & 1 & 1 \\ 1 & a^2 & a \\ 1 & a & a^2 \end{bmatrix} \begin{bmatrix} 0 \\ I_{a1} \\ 0 \end{bmatrix} \qquad (3)$$

$$I_{af} = I_{a1} = \frac{1.0 < 0^0}{Z_1 + Z_f}, I_{bf} = a^2 I_{a1} = \frac{1.0 < 240^0}{Z_1 + Z_f} \; and \; I_{cf} = aI_{a1} = \frac{1.0 < 120^0}{Z_1 + Z_f}$$

Since the sequence networks are short-circuited by self-impedance, $V_{a0} = 0, V_{a1} = Z_f I_{a1}$ and $V_{a2} = 0$

$$\begin{bmatrix} V_{af} \\ V_{bf} \\ V_{cf} \end{bmatrix} = \begin{bmatrix} 1 & 1 & 1 \\ 1 & a^2 & a \\ 1 & a & a^2 \end{bmatrix} \begin{bmatrix} 0 \\ V_{a1} \\ 0 \end{bmatrix} \qquad (4)$$

$$V_{af} = V_{a1} = Z_f, V_{bf} = a^2 V_{a1} = Z_f I_{a1} < 240^0 \text{ and } V_{cf} = aV_{a1} = Z_f I_{a1} < 120^0$$

$$V_{ab} = V_{af} - V_{bf} = V_{a1}(1 - a^2) = \sqrt{3Z_f} I_{a1} < 30^0, V_{bc} = V_{bf} - V_{cf} = V_{a1}(a^2 - a) = \sqrt{3Z_f} I_{a1} < -90^0$$

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$V_{ca} = V_{cf} - V_{af} = V_{a1}(a-1) = \sqrt{3Z_f I_{a1}} < 150^0$ and $I_{af} = \frac{1.0<0^0}{Z_1}$, $I_{bf} = \frac{1.0<240^0}{Z_1}$, and $I_{cf} = \frac{1.0<120^0}{Z_1}$

Figure 1 Single Line Diagram of NTA Mgbuoba 11kV Feeder Supply System (Simulated)

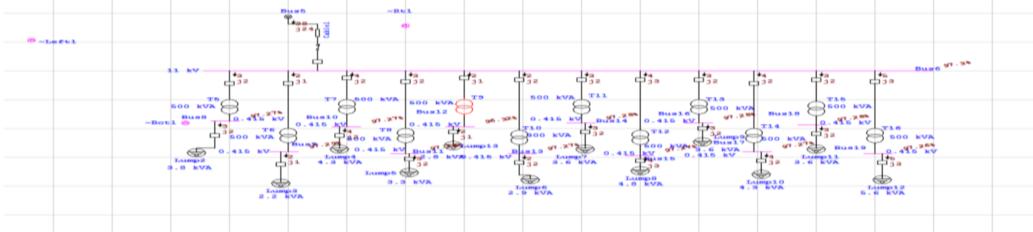

Figure 2 Single Line Diagram of the Study Case NTA Mgbuoba Distribution Analysis (Simulated)

The total fault current at bus 4 for a three-phase fault is given as:

$$I_{4(F)} = I^b_{4(F)} + I^0_{4(F)} \qquad (5)$$

$$= 1.935\angle 146.77^o + 2.113\angle 54.33^o = 2.803\angle 97.92^o$$

For Bus 1 then i = 1

$$V^0_{1(F)} = 0 - Z^0_{14} I^0_4 = 0 - (0.0112 + j0.11474)(0.9347\angle 97.94^o) = 0.108\angle 13.51^o$$

$$V^1_{1(F)} = V_{1(0)} - Z^1_{14} I^1_4 \qquad (6)$$

$$= 1.05\angle 0^o - (0.02254 + j0.17266)(1.3107\angle -78.83^o) = 0.822\angle 1.035^o$$

$$V^1_{1(F)} = 0 - Z^2_{14} I^2_4 = 0 - (0.02254 + j0.17266)(0.3813\angle -109.105^o) = 0.066\angle 11.66^o$$

For Bus 3 then i = 3

$$V^0_{3(F)} = 0 - Z^0_{34} I^0_4 = 0 - (0)(0.9347\angle 97.94^o) = 0\angle 0^o$$

$$V^1_{3(F)} = V_{3(0)} - Z^1_{34} I^1_4 = 1\angle 0^o - (0.14333 + j0.53368)(1.3107\angle -78.83^o) = 0.282\angle 9.98^o$$

$$V^2_{3(F)} = 0 - Z^2_{34} I^2_4 = 0 - (0.14333 + j0.53368)(1.3813\angle 109.105^o) = 0.21\angle 4.07^o$$

For Bus 4 then i = 4

$$V^0_{4(F)} = 0 - Z^0_{44} I^0_4 = 0 - (0.00756 + j0.24138)(0.9347\angle 97.94^o) = 0.226\angle 6.146^o$$

$$V^1_{4(F)} = V_{4(0)} - Z^1_{44} I^1_4 = 1\angle 0^o - (0.13269 + j0.57694)(1.3107\angle -78.83^o) = 0.226\angle 6.137^o$$

$$V^2_{4(F)} = 0 - Z^2_{44} I^2_4 = 0 - (0.13269 + j0.57694)(0.3813\angle 109.105^o) = 0.226\angle 6.152^o$$

For Bus 6 then i = 6

$$V^0_{6(F)} = 0 - Z^0_{64} I^0_4 = 0 - (-0.01706 + j0.05554)(0.9347\angle 97.94^o) = 0.054\angle 25.02^o$$

$$V^1_{6(F)} = V_{6(0)} - Z^1_{64} I^1_4 = 1\angle 0^o - (0.06881 + j0.34726)(1.3107\angle -78.83^o) = 0.536\angle 0.033^o$$

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$$V_{6(F)}^{2} = 0 - Z_{64}^{2} I_{4}^{2} = 0 - (0.06881 + j0.34726)(0.3813\angle 109.105^{o}) = 0.135\angle 7.897^{o}$$

The phase currents for line between buses 1 and 4 are given as:

$$I_{14(F)}^{a} = 0.5297\angle -88.21^{o} \quad I_{14(F)}^{b} = 0.9082\angle -168.64^{o} \quad I_{14(F)}^{c} = 0.9550\angle -32.53^{o}$$

$$I_{34(F)}^{a} = 0.1536\angle -67.83^{o} \quad I_{34(F)}^{b} = 0.2543\angle -171.03^{o} \quad I_{34(F)}^{c} = 0.2653\angle 43.27^{o}$$

$$I_{64(F)}^{a} = 0.1928\angle -91.52^{o} \quad I_{64(F)}^{b} = 0.4714\angle -164.59^{o} \quad I_{64(F)}^{c} = 0.4603\angle 37.73^{o}$$

Case 1: Three–Phase faults created where the impedance connected to bus 4 are Z_{14}, Z_{34}, Z_{44}, and Z_{64} respectively. For $i = 1,3,4,6$ voltages at all buses. For bus 4, $V_{i(F)} = V_i(0) - z_{iKI_k = V_i(0) - Z_{i4}I_4}$. For $i = 1, k = 4$, $V_1(F) = V_1(0) - Z_{14}I_4$, For $i = 3; k = 4, V_3(F) = V_3(0) - z_{34}I_4$ and For, $i = 4, k = 4, V_6(F) = V_6(O) - z_{64}I_4$

Case 2: Line faults between bus 1 and bus 4 are given a:

$$I_{ik}(F) = \frac{V_{i(F) - V_{k(F)}}}{(Z_{ik})_{Actual}} = \frac{V_{i(F)}}{(Z_{14})_{Actual}}$$

$V_4(F) = 0, i = 1, k = 4$

Or

$$I_{14}(F) = \frac{V_{1(F)}}{(Z_{14})_{Actual}}$$

Consider a single line to ground fault (L-G) in phase a:

$$V_a = zfI_a . I_b = 0 \quad (7)$$

$$.I_c = 0, \text{ then } I_a^0 = I_a^+ = I_a^- = \frac{V_f}{Z_0 + Z_+ + Z_-} \quad (8) \quad If = \frac{3V_f}{Z_0 + Z_+ + Z_-} \quad (9)$$

Consider the scenario of phase 'b' and phase 'c' is connected to ground through fault impedance (Z_F). Thus, faults current on phase 'a' is: $I_a = 0,\ I_a^0 = I_a^+ = I_a^- = 0$

$$V_b = V_c = Z_f(I_b + I_c) \quad (10) \quad I_a^+ = \frac{V_f}{Z_2 + Z_0 + 3Z_f} \quad (11)$$

$$V_b - V_c = I_b Z_f \quad (12)$$

$$I_f = -j\sqrt{3I_a^{"} +} \quad (13)$$

IV. RESULTS AND DISCUSSION

The system consists of six buses, two generators and seven branches. All data were provided by Port Harcourt Electricity Distribution Company (PHEDC). The results are given in the following tables.

Table 1 Bus Voltages for Three-Phase Fault

Bus #	Symmetrical component techniques		MATLAB		Paul Anderson's solution	
	Magnitude p.u	Angle^o	Magnitude p.u	Angle^o	Magnitude p.u	Angle^o
4	0.0000	0.000	0.0000	0.0000	0.0000	0.000
1	0.7578	-2.150	0.7432	–2.2887	0.7078	–2.300
3	0.0752	26.600	0.0753	26.7700	0.0752	26.800
6	0.4027	-2.600	0.4027	–2.5905	0.4027	–2.600

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Table 2 Fault Currents for Three-Phase Fault

	Symmetrical component techniques		MATLAB		Paul Anderson's solution	
	Magnitude p.u	Angle°	Magnitude p.u	Angle°	Magnitude p.u	Angle°
Bus 4	1.6890	−77.040	1.6892	−77.05	1.6890	−77.000
1 to 4	1.0000	−79.900	0.9816	−80.09	0.9350	−80.100
3 to 4	0.2827	−63.400	0.2829	−63.23	0.2830	−68.200
6 to 4	0.4810	−79.190	0.4812	−79.18	0.4810	−79.200

Table 3 Bus Sequence Voltages for Single Line –to-Ground Fault

Bus #		Symmetrical component techniques		MATLAB	
		Magnitude p.u	Angle°	Magnitude p.u	Angle°
Positive Sequences	4	0.5842	1.340	0.5840	1.340
	1	0.9278	−0.479	0.9278	−0.479
	3	0.6130	2.5100	0.6128	−2.510
	6	0.7510	0.0400	0.7510	−0.046
Negative Sequences	4	0.4162	178.120	0.4164	178.110
	1	0.1224	−176.37	0.1225	−176.580
	3	0.3880	176.00	0.3887	176.030
	6	0.2490	179.90	0.2490	179.860
Zero Sequence	4	0.1698	170.70	0.1699	170.720
	1	0.0810	−163.35	0.0810	−163.360
	3	0.0000	0.0000	0.0000	0.0000
	6	0.0408	−151.84	0.0409	−151.850

Table 4 Fault Sequence Currents for Single Line-to-Ground Fault

		Symmetrical component techniques		MATLAB	
		Magnitude p.u	Angle°	Magnitude p.u	Angle°
Positive Sequences	Bus 4	0.703	−78.93	0.703	−78.93
	1 to 4	0.460	−83.60	0.455	−81.37
	3 to 4	0.118	−65.10	0.118	−65.11
	6 to 4	0.200	−81.10	0.200	−81.07
Negative Sequence	Bus 4	0.703	−78.93	0.703	−78.93
	1 to 4	0.389	−82.00	0.389	−81.97
	3 to 4	0.119	−65.10	0.118	−65.11
	6 to 4	0.200	−81.10	0.200	−81.07
Zero Sequence	Bus 4	0.703	−78.93	0.703	−78.93
	1 to 4	0.045	−63.90	0.045	−63.95
	3 to 4	0.000	0.00	0.000	0.00
	6 to 4	0.058	−62.84	0.058	−62.91
Fault Currents	Bus 4	2.109	−78.93	2.110	−78.93
	1 to 4	0.891	−81.90	0.887	−80.76
	3 to 4	0.237	−65.10	0.236	−65.11
	6 to 4	0.452	−77.60	0.457	−78.79

From the above tables, both results confirmed the final results of the system analysis provided in Paul Anderson's Book. Also, the admittance matrix formed in the hand calculations' part is almost identical to the matrix generated by Matlab using Hadi Saadat's codes.

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Table 5 Faults Occurrence, 2009

Faults Class	NTA, Mgbuoba	Ada George	Mothly Total
SLG	13	12	26
LL	5	10	17
DLG	4	5	3
3-PHASE	1	1	2

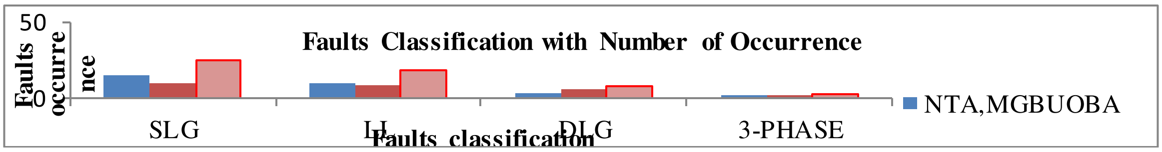

Figure 3 Faults Occurrence with Fault Classification for 2009

Table 6 Faults Occurrence, 2010

Faults Class	NTA, Mgbuoba	Ada George	Mothly Total
SLG	15	9	24
LL	10	8	18
DLG	3	5	8
3-PHASE	1	2	3

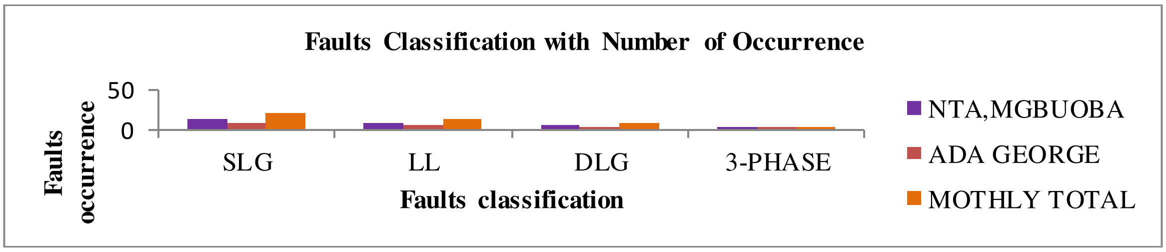

Figure 4 Faults Occurrence with Fault Classification for 2010

Table 7 Faults Occurrence, 2011

Faults Class	NTA, Mgbuoba	Ada George	Monthly Total
SLG	13	7	20
LL	7	6	13
DLG	5	4	9
3-PHASE	1	1	2

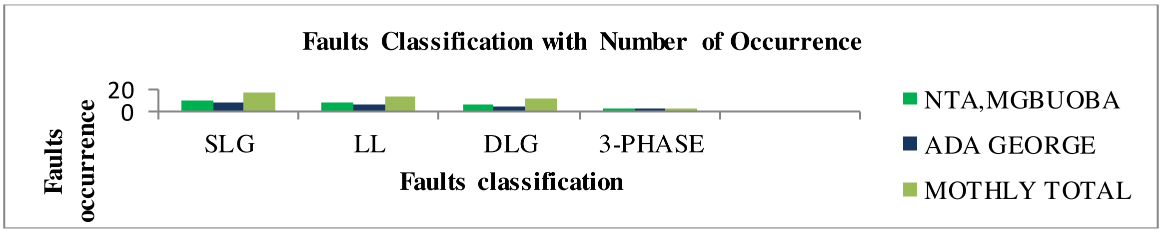

Figure 5 Faults Occurrence with Fault Classification for 2011

Table 8 Faults Occurrence, 2012

Faults Class	NTA, Mgbuoba	Ada George	Mothly Total
SLG	9	8	17
LL	7	6	13
DLG	6	5	11
3-PHASE	1	1	2

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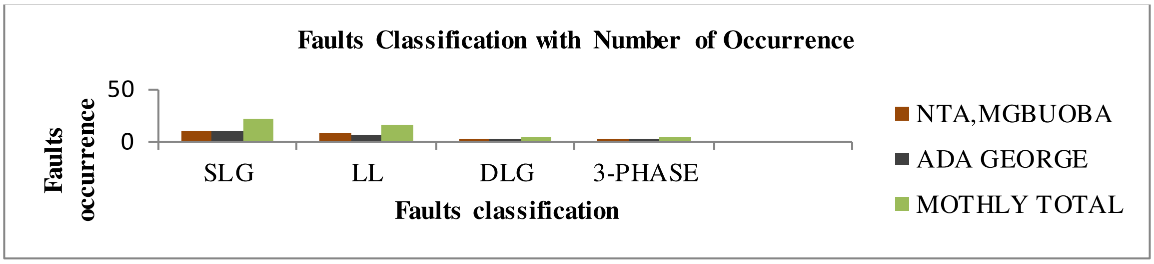

Figure 6 Faults Occurrence with Fault Classification for 2012

Table 9 Faults Occurrence, 2013

Faults Class	NTA, Mgbuoba	Ada George	Mothly Total
SLG	11	10	21
LL	9	7	16
DLG	2	3	5
3-PHASE	1	3	4

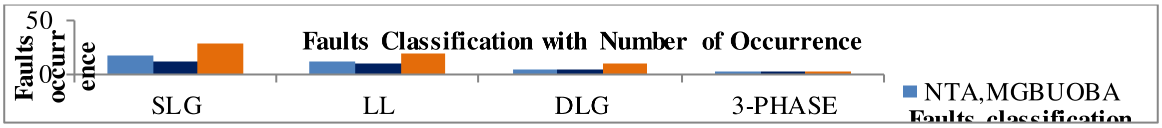

Figure 7 Faults Occurrence with Fault Classification for 2013

Table 10 Faults Occurrence, 2014

Faults Class	NTA, Mgbuoba	Ada George	Mothly Total
SLG	17	11	28
LL	11	9	20
DLG	4	5	9
3-PHASE	1	1	2

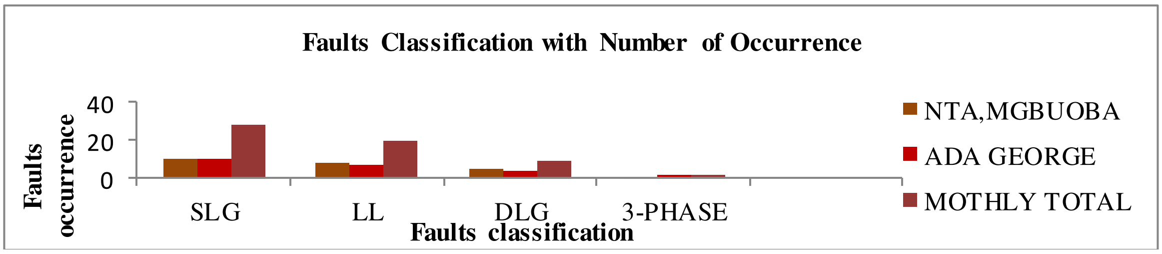

Figure 8 Faults Occurrence with Fault Classification for 2014

Table 11 Faults Occurrence, 2015

Faults Class	NTA, Mgbuoba	Ada George	Mothly Total
SLG	10	10	28
LL	8	7	20
DLG	5	4	9
3-PHASE	1	2	2

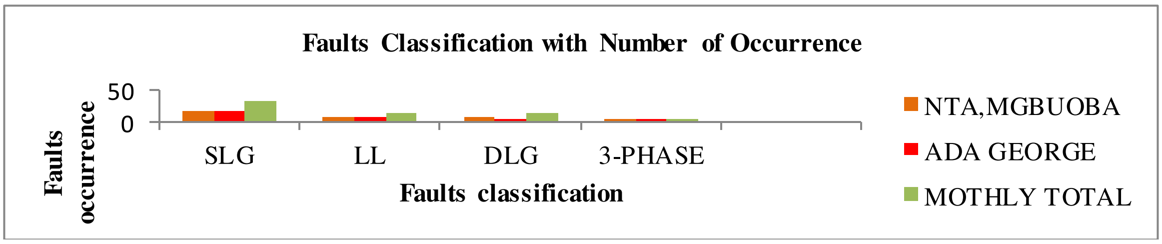

Figure 9 Faults Occurrence with Fault Classification for 2015

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Table 12 Faults Occurrence, 2016

Faults Class	NTA, Mgbuoba	Ada George	Mothly Total
SLG	16	15	31
LL	8	6	14
DLG	7	5	12
3-PHASE	2	2	4

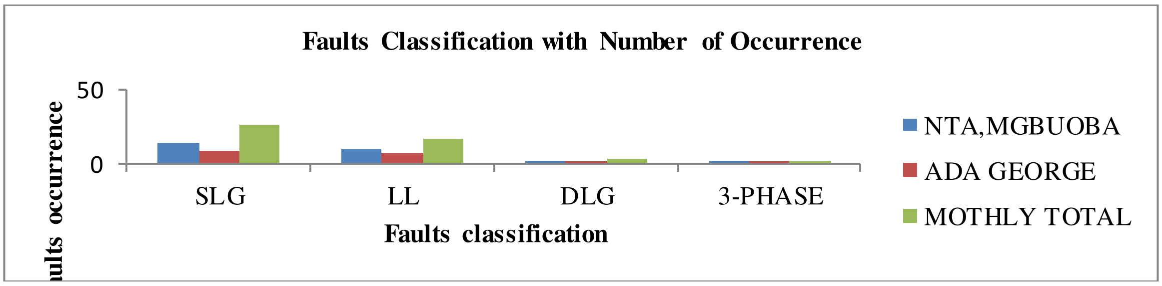

Figure 10 Faults Occurrence with Fault Classification for 2016

Table 13 Faults occurrence, 2017

Faults Class	NTA, Mgbuoba	Ada George	Mothly Total
SLG	14	9	26
LL	10	7	17
DLG	2	1	3
3-PHASE	1	1	2

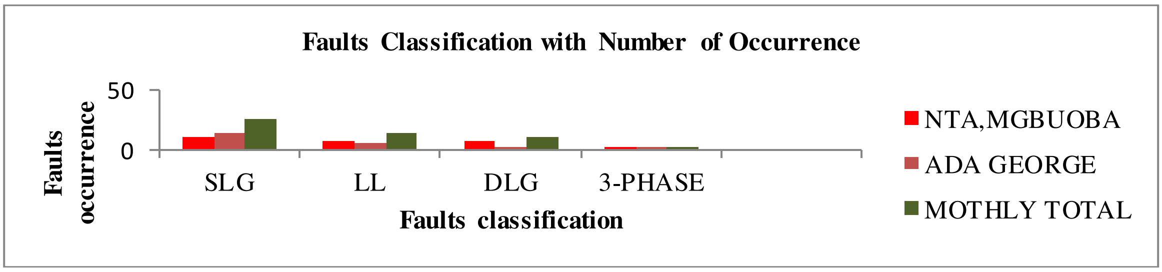

Figure 11 Faults Occurrence with Fault Classification for 2017

Table 14 Faults Occurrence, 2018

Faults Class	NTA, Mgbuoba	Ada George	Mothly Total
SLG	11	14	25
LL	7	6	13
DLG	7	3	10
3-PHASE	1	2	3

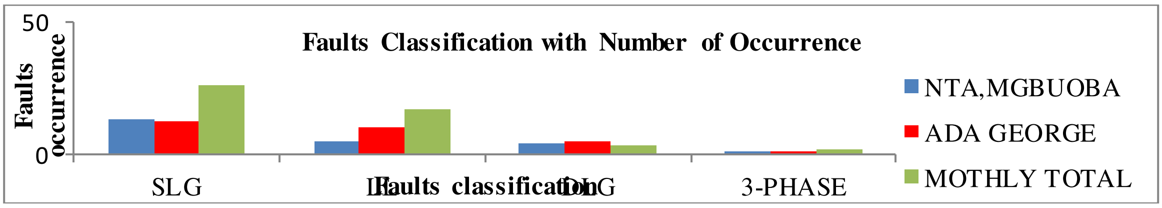

Figure 12 Faults Occurrence with Fault Classification for 2018

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V. CONCLUSION

This work was carried out at NTA Mgbuoba with a single line diagram translated to six (6) bus system. The analysis was carried out using impedance matrix method tied to symmetrical components techniques. The results were compared with software solutions to validate the impedance matrix method tied to symmetries technique' accuracy. The error was acceptable and below 0.1 p.u. for all types of fault.

Since phases B and C are in contact in line-to-line fault, the voltages at both phases are equal. The fault currents are passing from B to C. in phase A, the current is equal to zero compared to the fault current. In double line-to-ground fault, Phase B and C voltages are equal to zero. The faulted current is flowing through both phases only. In addition, this type of fault is the most sever fault on the system which can be seen from its current value.

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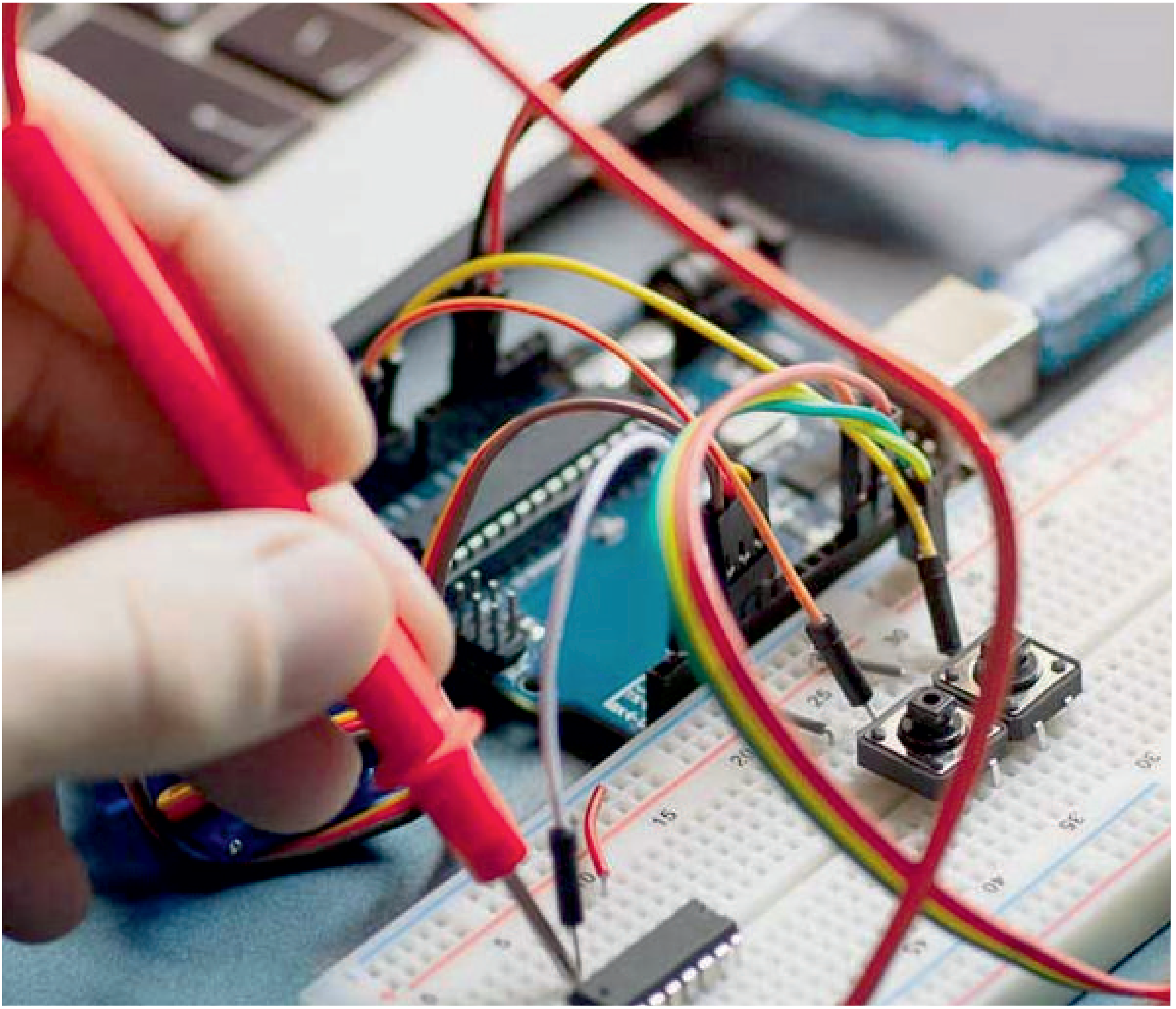

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