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Effective Protection Scheme for a Typical 33/11kV Injection Substation

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ABSTRACT: This study enhanced the protection scheme of Marine Base 2 X 15MVA, 33/11kV injection substation. The enhancement was achieved by collecting primary data from Port Harcourt Electricity Distribution Company with others realized from hand calculations to determine the ratings of various components of the scheme. Short circuit analysis was also conducted and the values became the inputs with which simulation was done in Electrical Transient Analyzer Program 12.6 software to verify the sensitivity of relays in the scheme. The table value for verification of lightning arresters and protective margin indicated that discharge current was 0.7996KA meaning that the available 5KA lightning arresters in use are adequate and protective margin of 145% is adequate as it is >20%. The table value of voltage gradients indicated that E step (tolerable) for faults of duration < 3seconds and sustained faults are 305.8V and 9.135V respectively while E touch (tolerable) for faults of duration < 3seconds and sustained faults are 308.1V and 9.03375V respectively showed that they are good as no one is higher than the reference values. The table value for transformers differential protection (Scenario1) showed that a matching current transformer of ratio 3.280A/4.374A represents a mismatch. Scenario 2 of the transformer differential protection is improved protection as it showed a matching current transformer ratio of 4.921A/4.374A. Report from verification of relay operation, scenario 1 showed that T1R2 and T2R2 failed to trip their respective circuit breakers under fault condition while scenario 2 relay operation report showed that T1R2 and T2R2 tripped normally meaning that scenario 2 relay operation has provided enhanced protection as tripping violation was eliminated.

KEY WORDS: Relay, Feeder, Injection Substation, Protective device, Lightning Arrester.

I. INTRODUCTION

The injection substation is a substation where a step down of higher voltage to a lower voltage is perfected as transmitted in densely populated dwellings. To serve the densely populated areas, transformers whose capacities are in the MVA value are always used. The injection substation comprises a set of complex electrical devices which basically include circuit breakers, current transformers, voltage transformers, bus bars and power transformers in a confined place. Many substations usually act as a connecting point of systems and/or areas that operate at different voltage levels. Such substations include power transformers to scale the voltage of one area to match the voltage of the adjacent area. In order to provide adequate and sufficient reliability to the overall system, protective devices are usually installed to detect abnormalities and react accordingly in a coordinated manner with other devices [1]. Transformers generally are the most important component in the transmission of electricity as they vary the voltage level as required.

Each control panel is usually connected to a defined fascia annunciation compartment which in turn alerts the operator by means of alarm. The annunciation may be classified or grouped into trip annunciation and warning annunciation [2]. This scenario describes the clear picture of power system components coordination which represents an overview of the power system from the generator to the customer with a deliberate attempt to make room for efficient power flow [3]. Due to high cost in investing on power system, adequate care has to be taken to make equipment operate normally at peak efficiency, eliminate damage to life and property and provides reliable uninterrupted service of quality. A relay can be seen as an electrical device that responds to its input information in a determined manner and by the virtue of its contact operation, initiates a sudden change in the corresponding control circuits [4].

Various power apparatus must always be connected and provided with adequate protection in the control room. Equipment devices in the switchyard are usually connected to the individual protective relays in the control room. Every protection or control function requires a distinct or specific wire and a distinct physical termination at the required relay [5]. The occurrence of faults in the grid becomes inevitable as the grid attains complexity. In power system, overloading resulting to excessive current higher than the rated value and short circuit resulting to abnormal

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current usually persist. These conditions pose a serious threat in the grid system arising from heavy current, which may cause serious damage to both the healthy and unhealthy portions of the grid, and even lead to the loss of synchronism and hence the collapse of the whole grid. In the present day substation technology, protection is aimed at detecting and isolating quickly the unhealthy portion and selectively as quickly as possible.

II. RELATED WORK

Presently, very large capacity transformers are available because of improvement in technology. This has eventually lowered operation and maintenance cost of the power system. Generally, this cannot totally eliminate the possibility of interruption that would occur because of transformer breakdown. Although, adequate protection must be maintained to eliminate forced outages even if it is well known that during the process of design, manufacture and installation of the transformer adequate precaution has been observed. Good knowledge of faults that the transformer may be subjected to while in service, and their causes and effects is very imperative [6].

A buchholz relay can be seen as a safety device which is capable to sense the accumulation of gas in large oil-filled transformers that can produce alarm on slow accumulation of gas or disengage the transformer if gas evolves speedily in the transformer oil [7]. A CT is normally installed at the earthing cable connecting between the frame and the earthing point with the principal intention to energize an instantaneous earth fault relay to trip the switchgear, typically all the CB’s connected to the busbar [8]. As a unit protection with its zone constrained by location of current transformers, the differential protection scheme in principle is considered superior with respect to selectivity, sensitivity, and speed of operation when compared with directional comparison, phase comparison, or stepped distance schemes [9]. The Direct current distribution system is considered another very important or critical system [10].

The lightning protection system according to Peekate [11] is a complete system of protection specifically designed to protect structures and their contents (if any) from the effects of lightning. To ameliorate the risk of fast-rising high-current surges within the substation, two protection system characteristics such as prevention of direct strikes to any operational component within the substation and prevention of fast-rising high-current surges from entering the substation through the incoming or outgoing lines are required [12]. Furthermore, lightning surges may also cause dangerous electromagnetic interference problems to low voltage systems and especially to electronic devices [13]. Lucas[14] listed several system voltages and their breakdown voltage characteristics as:

Table 2.1 Breakdown Voltage Characteristic

System Voltage	I.E.C Impulse Withstand Voltage
11kV	75kV
33kV	170kV
66kV	325kV
132kV	550kV
275kV	1050kV

Every power transformer must be protected with high - and low - sides lightning arresters. Shield wires and lightning arresters are essentially the basic means of overvoltage protection for substations and transmission lines [15]. Good lightning protection needs substation shielding and surge arresters to function [16]. In a substation, surge arrester is usually located at the section of the substation from which the incoming transmission lines are received and it becomes the threshold equipment of the substation. Surge arresters are also installed close to the transformer terminals phase to ground [17]. Substation protection from lightning may take any of the three methods which include: use of masts, use of both of masts and shielding wires, or use of shielding wires. However, heavy faults may occur in substation because of cut shielding wires. Secondly, the use of shielding wires is highly exorbitant compared to the use of masts. Again, if the tip of mast becomes largely less, then the mast attracts lightning flashes quicker or earlier than the shielding wire, hence, are considered more than shielding wires for lightning protection for substations [18]. A typical size of mesh is of 4m x 5m of earthing conductor. These meshes are connected to several earth electrodes of size 1.9cm x 3m driven at intervals[19].

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III. MATERIALS AND METHODS

3.1 Materials

The data needed were collected from Port Harcourt Electricity Distribution Company in Nigeria to analyse and investigate protection status of Marine Base 2 X 15MVA, 33/11kV injection substation as a test case. The test case being a conventional power injection substation chosen for this research has four outgoing 11kV feeders known as Churchill (formerly Borikiri), Nigerian Port Authority (NPA) (formerly Flour Mill), Amadi North and Station Road with average maximum load in the order of 3.4MW, 2.9MW, 3.7MW and 3.8MW respectively for the four 11kV feeders. The procedure for actualizing this goes as follows.

3.2 Methods of Analysis

All data pertaining current transformers, station earthing, relays and other relevant data collected were used for analysis. With the use of the available data, well guided hand calculation method was used to verify the protection level of lightning arrester, voltage gradients and transformer differential protection while protective relays sensitivity was verified with the use of short circuit method in Electrical Transient Analyzer Program (ETAP) 12.6 software.

Table 3.1 Relevant Data for Analysis

S/N	Parameter	Unit/Dimension
1	Nominal Rated Voltage	33kV
2	Highest System Voltage	36kV
3	Base MVA	100
4	Flashover Voltage For 33kV, 3units	Approx. 215kV
5	BIL For 33kV (British Standard BIL)	200kV
6	Protective Margin	≥ 20%
7	T1 Impedance	11.1%
8	T2 Impedance	10.7%
9	E Step (Tolerable) For Faults Less Than 3sec	310V
10	E Step (Tolerable) For Sustained Faults	10V
11	E Touch (Tolerable) For Faults Less Than 3sec	310V
12	E Touch (Tolerable) For Sustained Faults	10V
13	15MVA Transformer Primary CTR	300/5
14	15MVA Transformer Secondary CTR	1200/5
15	Lightning Arrester Rating	5kA
16	Soil Resistivity Near Surface of the Ground	2.5Ω/M

3.3 Relay Protective Technology and other protective devices at Marine Base 2 X 15MVA, 33/11kV Injection Substation.

Protective devices in use at Marine Base 2 X 15MVA, 33/11kV injection substation include: IDMT 3sec. electromechanical relay (CDG type) for over current (OC) and earth fault (EF) protection, sky wire run across the power transformers, lightning arresters on both lines, direct on- line rectifier unit for DC supply etc.

3.4 Station Tripping Unit (DC unit)

The station has a direct on- line rectifier unit for DC supply. This means to note the behavior of the DC unit in the event of the miniature circuit breaker (MCB) cutting supply due to trip while there is supply at the station and outgoing 11kV feeder is on, feeder will fail to trip as the rectifier is temporarily disconnected from the supply source.

3.5 Switch Yard Sky Wire

Visual check was conducted on the switch yard to determine if sky wire existed and its continuity to ascertain its reliability when connected to a healthy earthing system (effectively earthed system). This was in agreement with the

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assertion of Mital[5] that says a visual check must be conducted on the physical layout of the sky wire across the switch yard power equipment.

3.6 Protection Level of Lightning Arresters

The following parameters are realized to ascertain the true status of the lightning arresters in use at Marine Base 2 X 15MVA, 33/11kV injection substation:
nominal voltage = 33kV, highest system voltage = 36kV. For an effectively grounded earthing at 80% rating;
rating of lightning arrester = $Highest\ system\ voltage\ X\ 0.8$ (3.1)
For an effectively grounded earthing at 85% rating;
rating of lightning arrester = $Highest\ system\ voltage\ X\ 0.85$ (3.2)
Ratings using equations 3.1 and 3.2 as both are recommended Lightning Arrester voltage rating in B.S.S.
Residual voltage resulting from equation 3.2 becomes:
Residual voltage = $(Highest\ system\ voltage\ X\ 0.85)\ X\ 3.$ (3.3)
Power frequency spark-over voltage = $(Highest\ system\ voltage\ X\ 0.85)\ X\ 1.6$ (3.4)
Discharge current, $i_a = \frac{2el-ea}{Z}$ (3.5)
Where $i_a = Discharge\ current, el = Voltage\ of\ a\ travelling\ wave,$
$ea = Residual\ voltage\ of\ lightning\ arrester$
$Z\ becomes\ Surge\ impedance\ of\ the\ line(\ generally\ 400\ ohms)$. The value of el is usually found by the line insulator string flash over characteristics. From equation 3.5, a discharge current can be determined.
Protection level of the L.A. is located within 30feet of the transformer and can be expressed as:
PL = $1.15\ X\ (Residual\ voltage\ of\ Highest\ system\ voltage\ X\ 0.85) + 30$ (3.6)
Impulse spark over-voltage = $Highest\ system\ voltage\ X\ 0.85\ X\ 3.6$ (3.7)
A protective margin of 15% for switching over voltages and 25% for lightning over voltages are ideal.
Protection level for lightning and switching surges are:
$Protection\ level = Impulse\ spark\ over - voltage\ X\ 1.25$ (3.8)
The highest system voltage L.A. realized from equation 3.4 usually protects a transformer provided the basic insulation level (BIL) of the transformer is higher than protection level for lightning and switching surges as may be realized from equation 3.7 and then select the nearest B I L for 33kV to correspond to the value in equation 3.8.
Protective margin $= \frac{B.I.L}{Protection\ level}$ (3.9)
The result of equation 3.9 serves for switching and lightning and for temporary over voltages.

3.7 Determination of Earth Resistance

If fault current is established, then:
Minimum number of electrodes $= \frac{Fault\ current}{500}$ (3.10)
For an additional margin of 50%, number of electrodes is expressed as:
$Nr = 1.5\ X\ \frac{Fault\ current}{500}$ (3.11)
If the length of individual electrode is LR, total length is:
$LT = LC + LR = (L\ X\ NL + W\ X\ NW) + (Nr + Lr)$ (3.12)
Total area of earth mat may be realized as:
$A = L\ X\ W$ (3.13)
E step (tolerable) = $(R_K + 2R_F)I_K$ volts (3.14)
Where R_F = grounding resistance of one foot in ohms, P_S = resistivity of the soil nearthe ground surface in ohm-meter, R_K = resistance of the body in ohms, which is always 1000 ohms.
I_K = R.M.S current that flowvia the body in amps = $\frac{0.165}{\sqrt{t}}$ (3.15)
Wheret = duration of shock in seconds and is less than 3seconds = 0.009A for sustained faults.
For faults with duration less than 3seconds;
E step (tolerable) $= (1000 + 6P_s)\frac{0.165}{\sqrt{t}}$ (3.16)
E step (tolerable) $= \frac{(165 + P_S)}{\sqrt{t}}\ volts$ (3.17)
Therefore, sustained fault becomes:
E step (tolerable) $= (1000 + 6P_s)\ 0.009$ (3.18)
E step (tolerable) $= (9 + 0.054P_s)\ volts$ (3.19)

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E touch becomes:

E touch (tolerable) $= \left(R_K + \frac{R_F}{2}\right) I_K$ (3.20)

For faults of duration less than 3seconds:

E touch (tolerable) $= \left(1000 + \frac{3P_S}{2}\right)\frac{0.165}{\sqrt{t}}$ (3.21)

E touch (tolerable) $= \frac{(165 + 1.5P_S)}{\sqrt{t}}\ volts$ (3.22)

Sustained faults$= (1000 + 1.5P_S)0.009$ (3.23)

E touch (tolerable) $= (9 + 0.0135P_S)$ volts (3.24)

3.8 Differential Protection for a 15MVA, 33/11kV Dy1 Transformer

Primary full load current $= \frac{p}{\sqrt{3}xV}$ (3.25)

Where V = 33kV

Secondary full load current $= Primary\ full\ load\ current\ X\ CTR$ (3.26)

3.9 Verification of the Various 11kV Feeder Breaker Relays

Transformer impedance at Marine Base 2 X 15MVA injection substation base MVA may be defined as:

$Z_{P.U} = \frac{\%\ Z_1\ X\ Base\ MVA}{Transformer\ MVA}$ (3.27)

For a 3-phase fault on 11kV side:

Fault MVA $= \frac{Base\ MVA}{fault\ impedance}$ (3.28)

Fault current$= \frac{Fault\ MVA}{\sqrt{3}XV}$ (3.29)

WhereV = 11kV

For single phase to ground, earth fault impedance $= \frac{Transformer\ impedance}{3}$ (3.30)

Earth fault MVA $= \frac{Base\ MVA}{Earth\ fault\ impedance}$ (3.31)

Earth fault current $\frac{Earth\ fault\ MVA}{\sqrt{3}XV}$ (3.32)

3.9.1 Verification of Relay Sensitivity for 11kV Feeder Breaker Overcurrent Relay (OCR)

Secondary value of fault current $= Fault\ current\ X\ CTR$ (3.33)

Secondary full load current $= Full\ load\ current\ X\ CTR$ (3.34)

Plug Set (P.S) and Multiplier Plug Setting (MPS) become:

MPS $= \frac{Secondary\ value\ of\ fault\ current}{P.S}$ (3.35)

Actual operating time of relay becomes:

$t = TMS\ X\ \frac{0.14}{MPS^{0.02} - 1}$ (3.36)

3.9.2 Verification of Relay Sensitivity for 11kV Feeder Breaker Earth Fault Relay (EFR)

Secondary value of earth fault current $= Earth\ fault\ current\ X\ CTR$ (3.37)

3.10 Verification of Station Parameters Using Hand Calculation

With all the data required, hand calculation was used to investigate the selection of lightning arrester, voltage gradients and differential protection for the 2 X 15MVA, 33/11kV Dyl transformers at Marine Base injection substation.

3.10.1 Verification of Lightning Arresters for Marine Base 2 X 15MVA, 33/11kV Injection Substation

Nominal voltage = 33kV
Highest system voltage = 36kV
System is effectively grounded with 80% rating; rating of Lightning Arrester = 36 X 0.8 = 28.8kV
System is effectively grounded with 85% rating; rating of Lightning Arrester = 36X0.85 = 30.6kV
By British standard, any of the above values is recommended.

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Residual voltage of a 30.6kV Lightning Arrester = 30.6 X 3 = 110.16kV Peak
Power frequency spark over voltage = 30.6 X 1.6 = 48.96 = 49kV (rms)
For a 33kV system and 3units at tension, e_l is approximately 215kV.
Using equation 3.5, $Discharge\ current = \frac{2(215)-110.16}{400}$ 0.7996KA
5KA lightning arrester is ideal.
For the fact that Lightning Arrester is within 30ft close to transformer, protection level becomes
1.15 X 110.16 + 30 = 156.689kV
Impulse spark over voltage = 30.6 X 3.6 = 110.16kV Peak
Protective margin of 15% for switching over-voltages and 25% for lighting over-voltages are ideal for use.
Protection level for lightning and switching surges will be 110.16 X 1.25 = 137.7kV Peak
Therefore, 30.6kV lightning arrester can protect a transformer only if the BIL of the transformer is higher than 137.7kV. The closest BIL for 33kV to correspond to 137.7kV is 200kV (British Standard BIL)
Protective margin = $\frac{200}{137.7}$ = 1.45
145% stands for switching and lightning and for temporary over voltages.

3.10.2 Verification of Voltage Gradients for Marine Base 2 X 15MVA, 33/11kV Injection Substation

For faults of duration less than 3seconds where t = 0.3sec and $P_{S=2.5\Omega/m}$
E step (tolerable) = $\frac{(165+2.5)}{\sqrt{0.3}}$ = 305.8V
For sustained faults
E step (tolerable) = 9 + 0.054 X 2.5 = 9.135V
For faults of less than 3seconds
E touch (tolerable) = $\frac{(165+1.5\,x\,2.5)}{\sqrt{0.3}}$ = 308.1V
For sustained faults
E touch (tolerable) = 9 + 0.135 X 2.5 = 9.03375V

3.10.3 Differential Protection for the 2 X 15MVA, 33/11kV Dy1 Transformers at Marine Base Injection Substation(Scenario 1)

Primary full load current = $\frac{15\,X\,10^6}{\sqrt{3}X\,33\,X10^3}$ = 262.43A
Since current transformer ratio (CTR) available = 300/5
Secondary full load current = $262.43\ X\ \frac{5}{300}$ = 4.374A
For power the transformer, Secondary full load current = $\frac{15\,X\,10^6}{\sqrt{3}X\,11\,X10^3}$ = 787.30A
Since current transformer ratio (CTR) available = 1200/5
Full load current in CT secondary = $787.30\ X\ \frac{5}{1200}$ = 3.280A

3.10.4 Differential Protection for the 2 X 15MVA, 33/11kV Dy1 Transformers at Marine Base Injection Substation (Scenario 2)

Primary full load current = $\frac{15\,X\,10^6}{\sqrt{3}X\,33\,X10^3}$= 262.43A
Since current transformer ratio (CTR) available = 300/5
Secondary full load current = $262.43\ X\ \frac{5}{300}$ = 4.374A
For the power transformer, Secondary full load current = $\frac{15\,X\,10^6}{\sqrt{3}X\,11\,X10^3}$ = 787.30A
Current transformer ratio (CTR) of 800/5 is selected. Then:
Full load current in current transformer (CT) secondary = $787.30\ X\ \frac{5}{800}$ = 4.921A

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3.11 Verification of Relays Sensitivity (Scenario 1)

Short circuit method was used in ETAP 12.6 software to ascertain the sensitivity of the relays at Marine Base 2 X 15MVA, 33/11kV injection substation. The available data needed became input data for the simulation as in Figures.3.1 to 3.10.

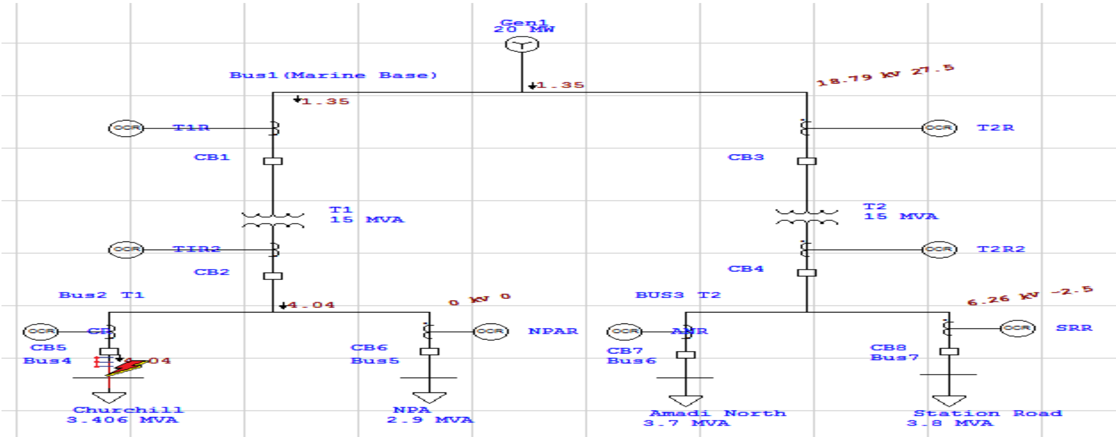

Figure 3.1 Churchill 11kV Feeder (Scenario 1)

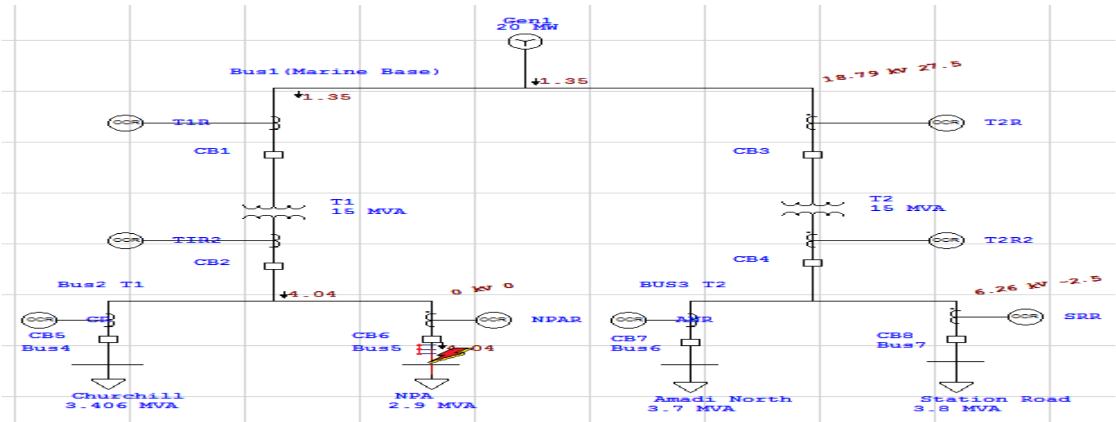

Figure 3.2 NPA 11kV Feeder (Scenario 1)

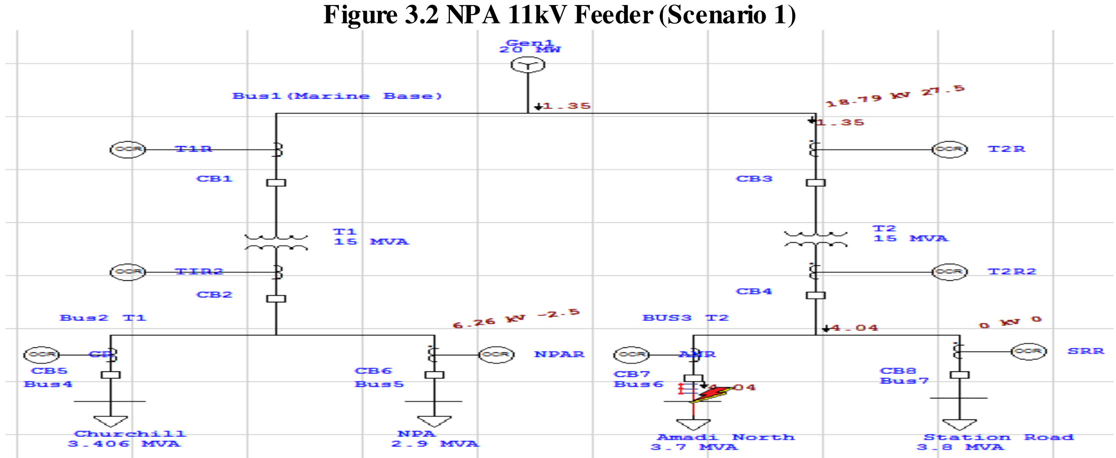

Figure 3.3 Amadi North 11kV Feeder (Scenario 1)

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Figure 3.4 Station Road 11kV Feeder (Scenario 1)

Figure 3.5 T1 11kV Incomer (Scenario 1)

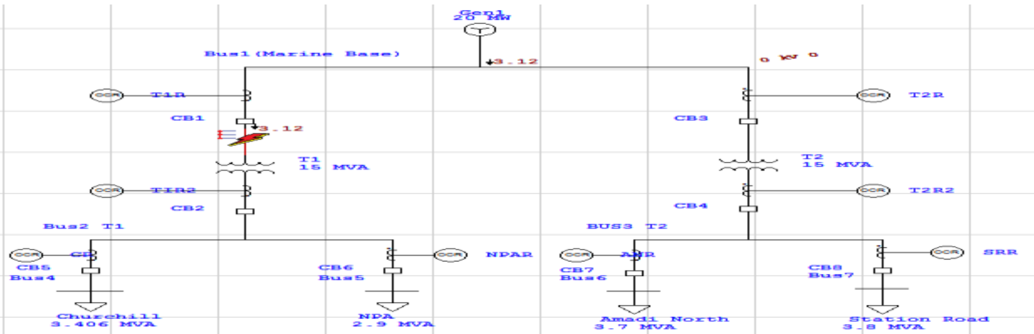

Figure 3.6 T1 33kV Breaker (Scenario 1)

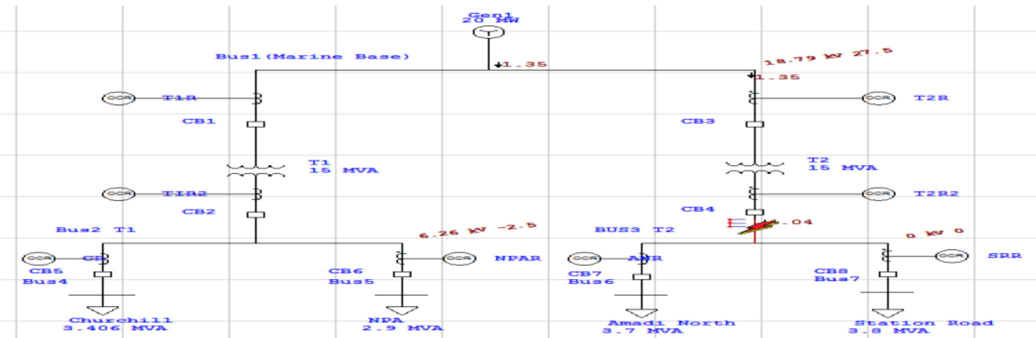

Figure 3.7 T2 11kV Incomer (Scenario 1)

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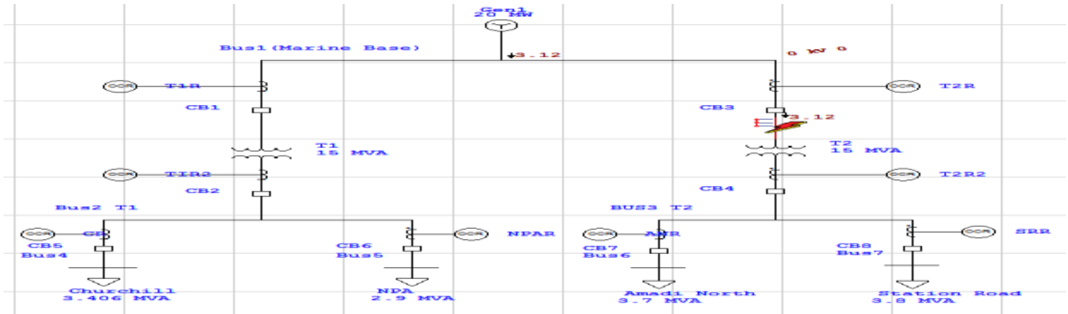

Figure 3.8 T2 33kV Breaker (Scenario 1)

3.12 Verification of Relays Sensitivity (Scenario 2)

Upon having all the data, only CTR of 1200/5 was replaced with 800/5 for the 11kV incomers and the incomers are modelled as shown in Figures 3.9 to 3.10.

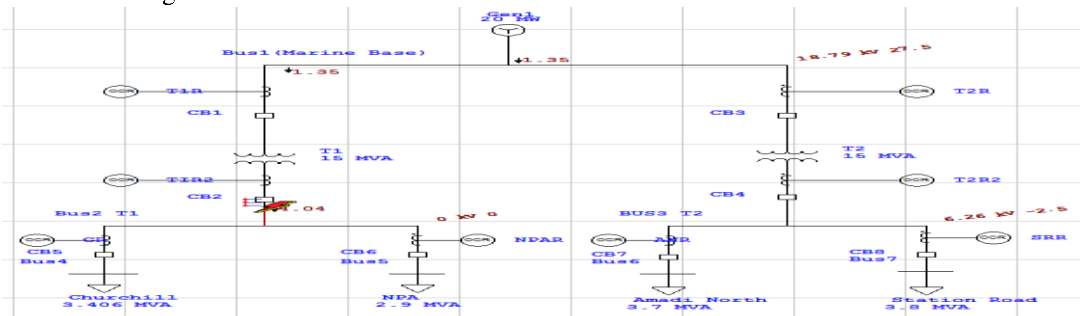

Figure 3.9 T1 11kV Incomer (Scenario 2)

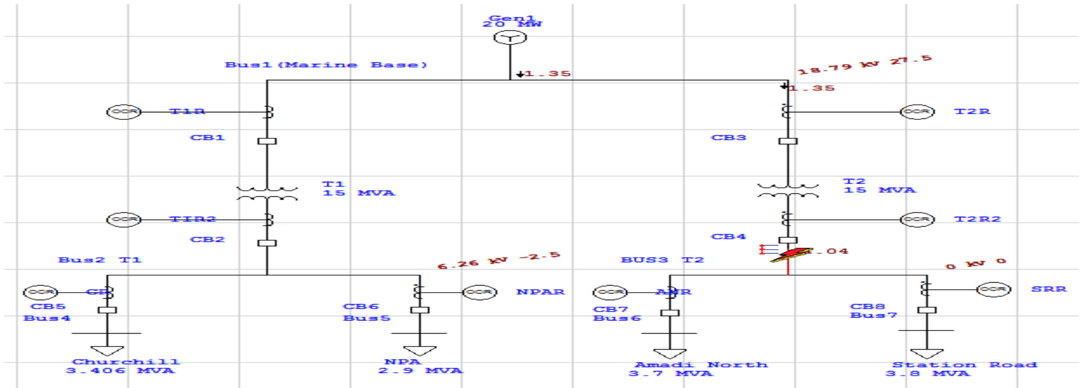

Figure 3.10 T2 11kV Incomer (Scenario 2)

IV. RESULTS AND DISCUSSION

4.1 Result Analysis

Hand calculation was used to verify the data collected in relation to lightning arresters and protective margin, voltage gradients and transformers differential protection while short circuit method was used in ETAP 12.6 software to verify the sensitivity of the available relays.

4.2 Analysis from Verification of Lightning Arresters Result

The result obtained from the hand calculation shows that:

I. Since the discharge current was 0.7996KA, a 5KA lightning arrester was selected for the protection of the transformers

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II. The protective margin was 145%

4.3 Analysis from Verification of Voltage Gradients Result

I. The result obtained from the hand calculation shows that:
II. E step (tolerable) for faults of duration less than 3seconds is 305.8V
III. E step (tolerable) for sustained faults is 9.135V
IV. E touch (tolerable) for faults of duration less than 3seconds is 308.1V
V. E touch (tolerable) for sustained faults is 9.03375V

4.4 Analysis from Differential Protection for the 2 X 15MVA, 33/11kV Dy1 Transformers at Marine Base Injection Substation (Scenario 1)

The result obtained from the hand calculation shows that:
I. The transformer secondary current transformer ratio (CTR) is 1200/5
II. Full load current in current transformer (CT) secondary is 3.280A
III. The transformer primary current transformer ratio (CTR) is 300/5
IV. Secondary full load current of current transformer (CT) from the primary side of the transformer is 4.374A
V. Current transformer (CT) mismatch occurred.

4.5 Analysis from Differential Protection for the 2 X 15MVA, 33/11kV Dy1 Transformers at Marine Base Injection Substation (Scenario 2)

The result obtained from the hand calculation shows that:
I. The transformer secondary current transformer ratio (CTR) is 800/5
II. Full load current in current transformer (CT) secondary is 4.921A
III. The transformer primary current transformer ratio (CTR) is 300/5
IV. Secondary full load current of current transformer (CT) from the primary side of the transformer is 4.374A
V. Current transformer (CT) matching occurred.

4.6 Analysis from Verification of Relays Sensitivity Result (Scenario 1)

The result obtained from the short circuit analysis using the available current transformer ratios (CTRs) on Marine Base injection substation shows that:
I. T1R2 failed to trip the circuit breaker when fault was introduced close to it
II. T2R2 failed to trip the circuit breaker when fault was introduced close to it
III. All other relays tripped their associated circuit breakers when fault was introduced close to each of them.

4.7 Analysis from Verification of Relays Sensitivity Result (Scenario 2)

The result obtained from the short circuit analysis using the available current transformer ratios (CTRs) on Marine Base injection substation shows that:
I. T1R2 tripped the circuit breaker when fault was introduced close to it
II. T2R2 tripped the circuit breaker when fault was introduced close to it

4.8 Lightning Arrester Verification Result

The results so obtained pertaining the present lightning arresters are presented in Table 4.1. However, a 5KA current rating of lightning arrester is actually the one in place which is able to protect the system.

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Table 4.1 Verification of Lightning Arrester and Protection Margin

Nominal Voltage(kV)	Discharge current(kA)	Lightning Arrester (kA)		Protection Margin (%)		Status
		Tolerable	Attained	Tolerable	Attained	
33	0.7996	5	5	≥ 20	145	> 20%

4.9 Voltage Gradients in the Vicinity of the Grounding System Verification Result

The results obtained pertaining the present voltage gradients are presented in Table 4.2. The calculated values are in line with the values provided by Port Harcourt Electricity Distribution Company.

Table 4.2 Verification of Voltage gradients in the Vicinity of the Grounding System

Voltage Gradients (V)	Tolerable (V)	Attained	Status
E step < 3sec	310	305.8	< 310
E step (Sustained fault)	10	9.135	< 10
E touch < 3sec	310	308.1	< 310
E touch (Sustained fault)	10	9.034	< 10

4.10 Transformers Differential Protection Result

The results obtained pertaining the present differential protection which is Scenario 1are presented in Table 4.3. A current transformer (CT) mismatch occurred. However, transformer secondary current transformer ratio (CTR) was replaced and a matching CT was achieved

.

Table 4.3 Transformer Differential Protection

Scenario	Primary CTRs	Secondary CTRs	Matching CT	Status
Scenario 1	300/5	1200/5	3.280A/4.374A	Mismatch
Scenario 2	300/5	800/5	4.921A/4.374A	Match

4.11 Relays Sensitivity Verification Result

The results obtained pertaining the present (Scenario 1) relays operation and improved relays operation (Scenario 2) are presented in Tables 4.4. The replacement of the transformer secondary CTRs actually made the transformers secondary current transformers (CTs) to trip the associated circuit breakers.

Table 4.4 Summary of Relay Operation Report for Scenarios 1 and 2

Feeder	Operating Time (ms)	
	Scenario 1	Scenario 2
Churchill	18.6	18.6
NPA	18.6	18.6
Amadi North	18.6	18.6
Station Road	18.6	18.6
T1R2	0	19.1
T1R	18.6	19.4
T2R2	0	19.1
T2R	18.6	19.4

4.12 Enhancement of Injection Substation Protection

It was noted that CT mismatch occurred while conducting a well guided hand calculation on the differential protection of the 15MVA transformers. However, correct CT matching was achieved after interchanging the present CTR of 1200/5 with another CTR of 800/5. Furthermore, both 11kV incomer relays failed to operate when fault occurred very close to them until the CTR of 1200/5 for each transformer was replaced with that of 800/5 and the relays operated accordingly.

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V. CONCLUSION

5.1 Conclusion

To a large extent, this research has been able to show that it is very essential to achieve improved protection for Marine Base 2 X 15MVA, 33/11kV Injection Substation. The data collected were used to conduct well guided hand calculation to verify and further improve on as required - the lightning arrester, step and touch voltages and transformer differential protection.

Also, short circuit analysis was used in ETAP 12.6 software to ascertain and enhance the relays operation of the injection substation. A CT mismatch occurred on the transformer differential protection. There was a wide gap between the secondary CT secondary line current of 3.280A and primary CT secondary line current of 4.374A. The replacement of CTR on the transformer secondary automatically closed the wide gap. A matching CT was achieved with the value as 4.921A/4.374A. Also, all the relays operated when fault was introduced thereby leaving two (2) relays out. The transformer secondary relays failed to operate on the introduction of fault. However, the CT value of 1200/5 was replaced with 800/5 and the relays operated accordingly.

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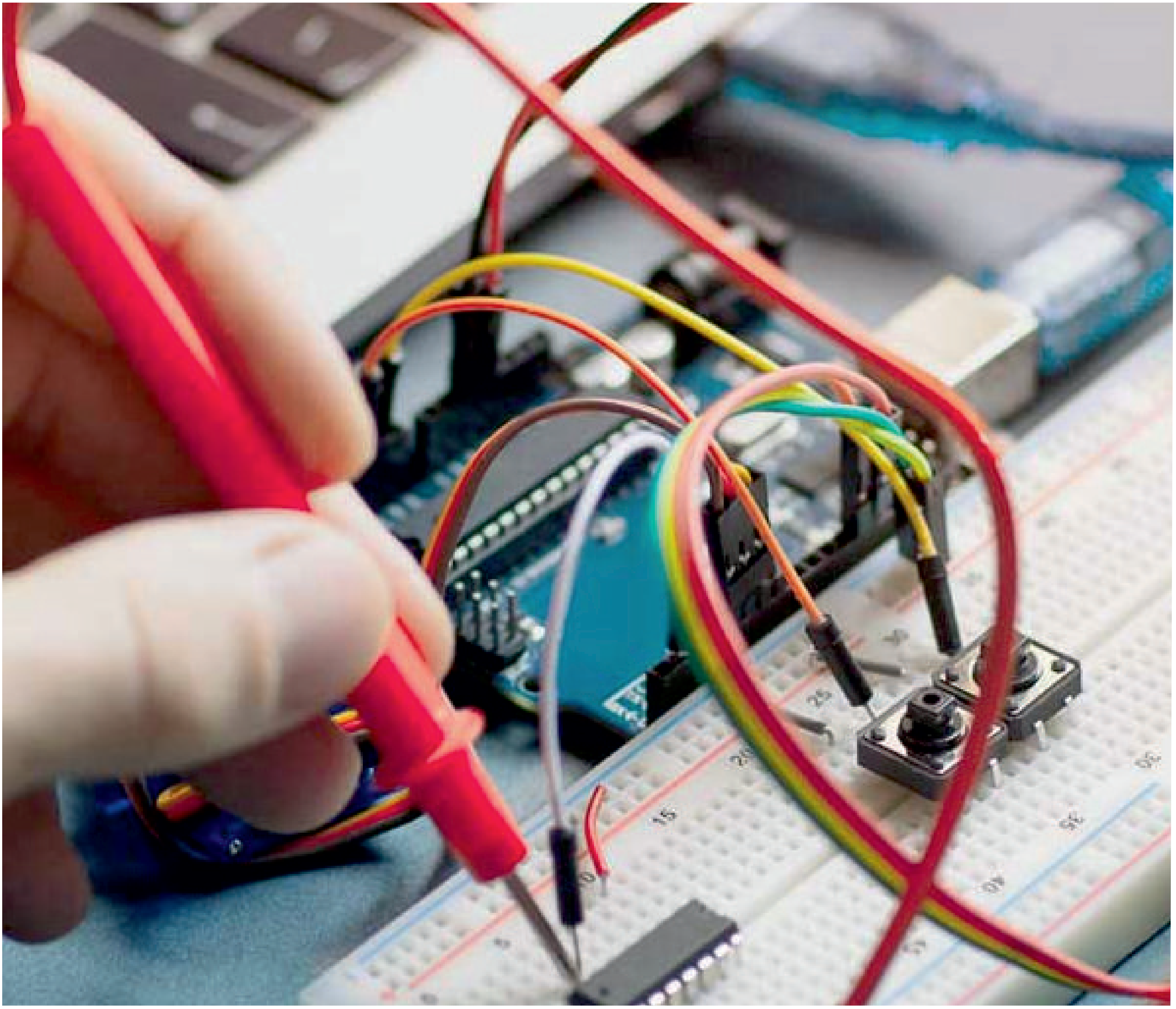

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