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Improved Protection for 33/11kv Injection Substation at Nzimiro, Portharcourt Zone 4, Old Gra, Port Harcourt.

KANIKWU, Ibietela W.[1], IDONIBOYEOBU, D.C.[2], and BRAIDE, S.L[3].

[123] Department of Electrical Engineering, Rivers State University, Port Harcourt, Nigeria

Corresponding Author: KANIKWU, Ibietela W.

ABSTRACT: *This research work considered the improved protection for 33/11KV i injection substation at zone 4, Nzimiro Old GRA, Port-Harcourt. The protection of the substation play an important role as a function designed primarily to prevent or minimize damage to equipment, maintain reliable and uninterrupted service of quality to the consumers. An existing data collected from Port Harcourt Electricity Distribution Company (PHEDC) were used for the case study, in order to investigate the level of voltage drop, losses by means of electrical transient analyzer tool (ETAP-version 12.6). Some data were served as input data for simulation in ETAP 12.6 to verify the sensitivity of relays (Case 1 and 2 respectively). The results obtained in case 1 indicate that T1, T2, and T3 failed to trip the circuit breaker when fault was introduced close to it while all other relays tripped their associated circuit breakers when fault was introduced close to each of them. Furthermore, the result obtained in case 2 indicate that T1, T2 and T3 tripped the circuit breaker when fault was introduced close to it and also all other relays tripped their associated circuit breakers when fault was introduced close to each of them. Therefore, case 2 relay operation was used to improved protection of the injection substation. However, for transformers differential protection (Case 1) shows a current transformer ratio of 4.374A/6.561A which is a mismatch. Similarly, for case 2 the transformer differential protection has been improved upon, as it shows a matching current transformer ratio of 6.561A/6.560A.*

KEYWORDS*: Power System Protection, Protective Relays, Differential Protection, Symmetrical Faults, Relay Sensitivity*

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I. INTRODUCTION

The injection substation at Zone 4, Nzimiro Old GRA, Port-Harcourt was built to be a professionally managed utility, supplying reliable and cost efficient electricity to every citizen of the area through highly motivated employees and state of the art technologies, hence the need for power system protection to ensure that this goal is met. The main function of the power system is to provide energy to the customers adequately and efficiently. In the normal situation, the power system is demanded to be highly efficient and safe. If any part within the system has failed, the amount of delivered power can be affected and huge economic losses can be induced, not to mention the safety issues that may follow a fault. Consequently, reliability evaluation of the power system is of significant importance.

In a power system substation, when a fault occurs, the post-fault phenomena are dynamic, and are usually involved with the connectivity between the energy source and the load [1]. These post-fault phenomena can be very complex depending on the system structure. Normally, the protection in the substation should react and isolate the faulted part successfully in this situation. In most of the traditional reliability studies, the protection systems are assumed to be perfect. This assumption makes the analysis and calculations much easier, but may lead to unrealistic results. The reality has shown that failures of the protection can lead to serious outages of the substation. Therefore, the reliability of the substation with protection failures will be the major concern of this study, [2]. The electrical power system consists of primary plants such as generators, transformers switchgears, transmission and distribution lines (overhead and underground, [3]. Capital investment involved in the acquisition of these primary plants is so great that proper precautions must be taken to ensure that the equipment operates optimally as possible at peak efficiencies and also that they are protected from accidents. Therefore electrical power system protection is a vital prerequisite for the efficiency of primary plants so that electrical power system is capable of satisfying the growth in the demand for electrical energy both economically and reliably. This aspect of engineering deals with the protection of electrical power system from faults, through the isolation of faulted parts from the rest of the electrical network [4].

Hence the objective of power system protection is to keep the power system stable by isolating only the components that are under fault through a pragmatic and pessimistic approach while leaving as much of the network as possible still in operation, using a specific protection scheme.

1.1 The aim of this research work

This research work is aimed at improving protection for the 33/11KV injection substation at zone 4, Nzimiro Old GRA, Port Harcourt.

1.2 Objectives of the Study

With respect to the aim of this research work, the objectives are:

i. Determine the line diagram/ data at Zone 4 for modeling and simulation using E-TAP.
ii. Run the network model in E-TAP environment using short circuit analysis technique.
iii. Determine and identify abnormal tripping sequence of the protection scheme.
iv. Remodel existing study case of short circuit analysis for reliable and efficient relay coordination system.

II. LITERATURE REVIEW

As stated by [5], in their book, the user of electricity believes that the power system is in steady state, imperturbable, constant and infinite in capacity. Yet the power system is subject to constant disturbances crested by natural causes and sometimes as a result of equipment or operator failure. Isolation of electrical faults in a power system means the correct and quick remedial action taken by protective relaying equipment. According to [1], protection of the system against damage is a function of their circuit breakers. Before the circuit breaker can open, its operating coils must be energized; this in turn requires that certain protective equipment shall be energized.

According to [6], which stated in his paper that relaying plays a vital role in maintaining system stability by clearing faults', as quickly as possible thus isolating faults which can be severe and lead to eventual loss of synchronism should the fault persist. This is the basic function of the relay, even though the operating coils can sometime see external fault as internal fault and thereby cause incurred tripping. Historically, more attention regarding reliability analysis has been put into power generation rather than into distribution systems thereby causing the greater contribution to the unavailability of electric power supply to customers but the liberalization of the power sector would make distribution reliability of more interest now than ever before [7].

. The fundamental objective of system protection is to quickly isolate a problem so that the unaffected portions of a system can continue to function and protective relaying is an integral part of the scheme. Protective relays are the decision making devices in the protection scheme. These relays have undergone, through more than a century, important changes in their functionalities and technologies, each change bringing it odds improvement in both technical and financial aspects.

The history of protective relays refers to more than a century ago. Some literatures say that the first protective relays were produced in 1902 [8], others refer to 1905 [9]. But whatever the date, the fact is that protective relays experienced an important revolution since the beginning of the twentieth century. In 1909, induction disk type inverse time current relays came into practice and the concept of directional discrimination of faults was incorporated in these protective relays [10] while differential relays was developed using pilot wires for conveying information from one end to the other end of the line [11]. All of the relays developed until the 1940's were electromechanical relays. These devices achieve very high precision and selectivity in the form of induction cup which operates and performs well for the purpose it was built.

The early 1940's showed the way into the development of relays using electronic devices [10]. These relays are known as static relays or solid state relays because they don't contain moving parts. The advent of transistor circuits opened the door to development of several new protection concepts like block comparator, phase comparator, etc. The major advantage of these relays was that no moving parts were needed for performing their intended functions. The operating speeds of these relays were also more than the speed of their electromechanical counterparts and their reset times were less than the reset times of electromechanical protective relays, in addition to these benefits the solid – state relays could be set more precisely [12].

The use of digital computers and microprocessor for protective relaying purposes has been engaging the attention of researchers since the late 1960's. Much literature reported digital relays shortly afterwards but the first microprocessor based relays offered as commercial devices was only in 1979 [12]. In that era, the efforts were concentrated to obtain a very high speed fault clearance. Different techniques and logarithms were proposed for the achievement of this objective, these include common hardware platforms, configuring the software to perform different functions [13].

In the late 1980's Multifunction digital relays were introduced to the market [13]. These devices reduced the product and installation cost drastically and has converted microprocessor relays to powerful tools in modern substations. In the 1990's the motion of integrated protection and control became very popular and benefited full advantage of microprocessors technology for protection, monitoring control, disturbance and event handling and communication. The relays volumes as well as wiring were significantly reduced due to the integration of functions and the use of serial communication.

Differential Protection is based on Kirchhoff's first law. The sum of the current flows into a circuit should be equal to the sum of the current flows out. This protection checks the difference between input and output current for electrical components. If the difference of the current is beyond the normal value, the differential protection will see the fault, and send a trip signal to the corresponding circuit breakers through the telecommunication channel. Consequently, the tripping circuit breakers will isolate the faulted components from the healthy part, [1]. According to the principle of differential protection, at least two current transformers are needed to provide the current measurement, while a telecommunication channel is used to transmit these values. Based on the components that a differential protection protects, differential protection can be further classified into several types. In Fig 2.1, the field differential and line differential protection schemes are shown. There are two substations connected with one overhead line in the figure. On the left side, the red and blue blocks with dotted lines represent the bay differential protection zones. When a fault occurs within the zone, it will trip the corresponding circuit breakers. For example, if a fault occurs within the red block area, the three current transformers will offer the measurements, which have a larger difference than in the normal situation. The field differential protection will then see the fault, and send the trip signal to circuit breakers CB_A and CB_B. The faulted part then is isolated from the other part of the system, [1].

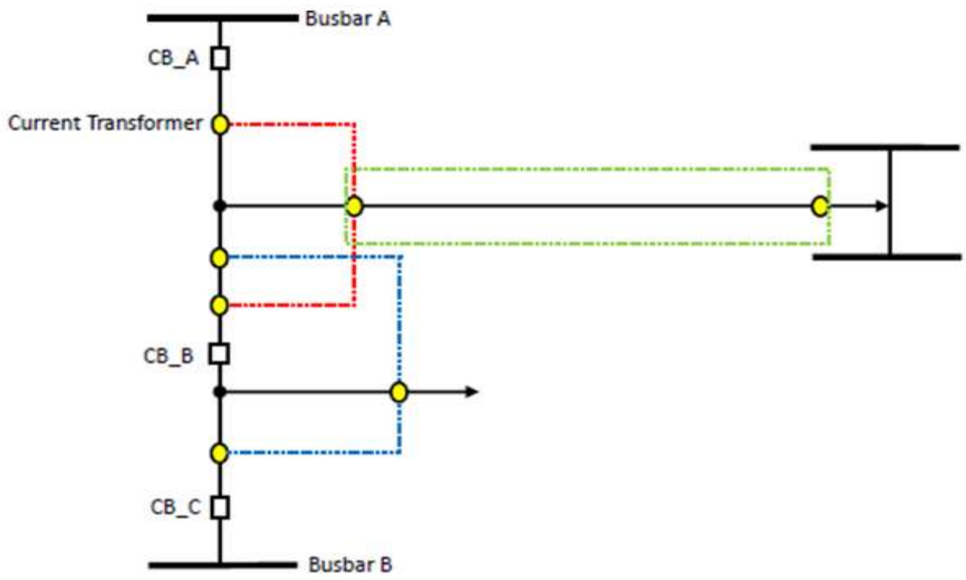

Figure 2.1: Field Differential Protection & Line Differential Protection Scheme

After a protection system successfully detects the fault in the system, it will send a signal to the associated circuit breakers. The circuit breakers will then respond to the command and trip. In reality, there is a chance that the circuit breakers refuse to trip, or have such a long delay that the protection system considers it to be failed. When having a circuit breaker failure, a function called circuit breaker failure function is applied to make sure that the faulted part is isolated. In the Netherlands, this circuit breaker failure function is called SRBV, which is short for "Schakelaar Reserve Beveiliging". There are two criteria that have to be satisfied to activate the circuit breaker failure function:

Criteria 1: Both the primary protection and the back-up protection see the fault.

Criteria 2: In one of the protections the circuit breakers are not tripped successfully.

Take the line in Fig 2.1 as an example, the line is protected by two different protection systems. The primary protection is the differential protection, while the back-up protection is the distance protection in the direction of the blue arrow.

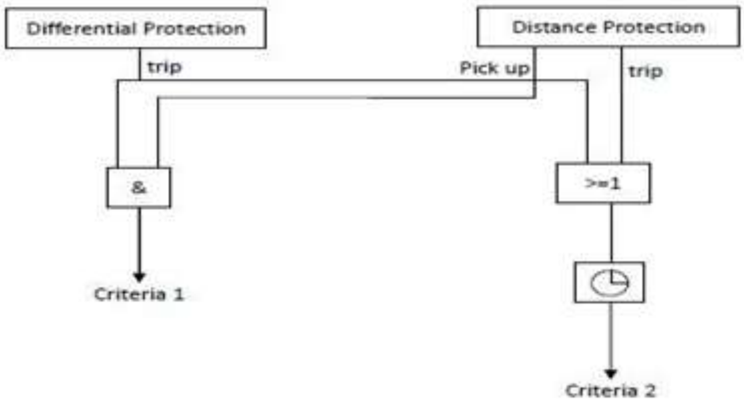

Figure 2.2: Circuit Breaker Failure Function Principle

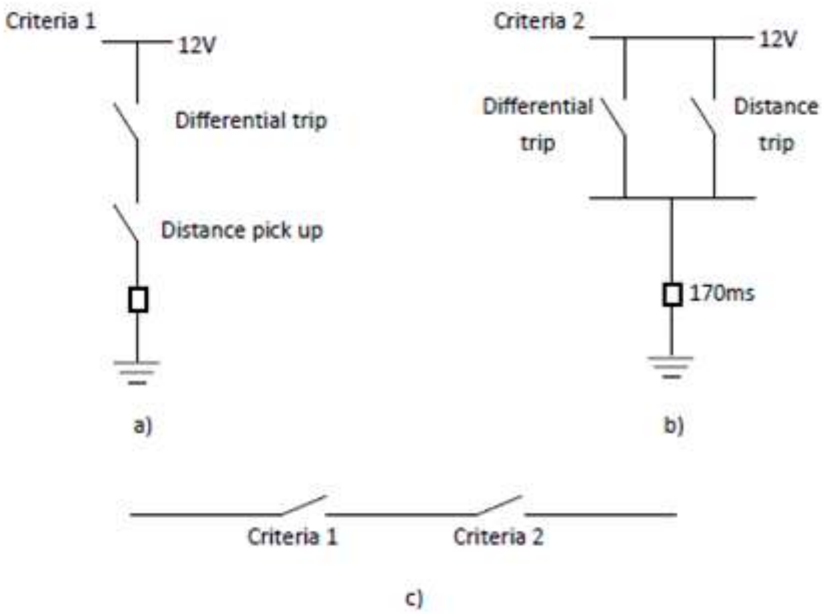

Figure 2.3: Circuit Breaker Failure Function Criteria

The two criteria are shown in Fig 2.2 and Fig 2.3. Fig 2.3 explains the circuit breaker failure function by the AND Gate and OR Gate, while Fig 2.3 explains the same principle by a series and parallel circuit connection. As can be seen from the Fig 2.2, for the differential protection, when it sees the fault, it will pick up the fault and trip at the same time. For the distance protection, the pick-up and trip process can happen at a different time.

The two criteria are in series connection, which is shown in Fig 2.3 c). This demonstrates that the circuit breaker failure function will only be activated when the two criteria are satisfied at the same time. If a fault occurs on the line in Fig 2.1, the differential protection and distance protection should all pick-up the fault at the same time, and the differential protection will trip immediately. The criteria 1 is satisfied. As shown in Fig 2.2 a). At the same time, criteria 2 will also be satisfied after a time delay 170ms, as shown in Fig 2.2b). If the circuit breakers that are associated with the differential protection system work successfully, the fault will be cleared within 170ms. Then criteria 1 will not be satisfied and the circuit breaker failure function will not be activated. If the circuit breakers tripped by the differential protection system fail, the fault will remain in the system after 170ms. The criteria 1 and criteria 2 will both be satisfied and the circuit breaker failure function will be activated. Care has to be taken that the circuit breaker failure function will only be activated when the circuit breakers fail. If the protection system fails, the criterion is not satisfied and the circuit breaker failure function will not react, [14].

III. MATERIAL AND METHODS

3.1. Research Materials Used

For purpose of efficient and reliable operation of power system the control of voltages and reactive power should satisfy statutory condition, therefore data are collected and investigation of this study, these include:

i. Collection of data from Port Harcourt Electricity Distribution (PHEDC) and Transmission Company of Nigeria (TCN).

ii. Collection of line diagram from PHEDC to model in ETAP tool for investigation

.

Table 3.1 Available Data for Types of Feeder, Length and Loading.

S/N	TYPES OF FEEDER	LENGTH	LOADING
1.	Amadi South Feeder	10.86k m	4.6MW
2.	Owerri Road Feeder	7.45km	2.4MW
3.	Mile One Feeder	7.02km	4.3MW
4.	Trans-Amadi Residential Area Feeder	22.88km	5.1MW
5.	Old Diobu Feeder	7.82km	6.1MW

Source: PHEDC

One of the major causes of almost all the power system disturbance is under voltage. Reactive power (Var) cannot be transmitted very far especially under heavy load conditions so it must be generated close to the point of consumption. This is because of the difference in the voltage on a power system +/-s percentage of nominal and this small voltage difference does not causesubstantial reactive power (Var) to flow over long distances, so if that reactive power (Var) is not available at the load centre, the voltage level goes down. Under voltage can cause excess wear and tear on certain devices like motor as they will tend to run overly hot if the voltage is low. The table below can represent the types, rating of equipment used in the 33/11KV Port Harcourt Zone 4 injection substation.

Table 3.2: Available Data use for the Types, Rating of Equipment used in the 33/11KV Port-Harcourt Zone 4 Injection Substation

S/N	COMPONENT	TYPE	RATING
1.	Power Transformers	T_1 Current Transformer	15 MVA each
2.	Circuit Breaker	SF6	
3.	Feeders		1250A each
4.	Isolators		1630A each

Source: PHEDC

Table 3.3: Available Data for Components used in 33/11KV Port Harcourt Zone 4 Injection Substation

COMPONENTS	TYPE	RATING	
Power Transformer		Minimum	Maximum
	Transformer 1	15MVA	15MVA
	Transformer 2	15MVA	15MVA
Circuit Breakers	CB-1	145KV/125A/3600A	
	CB-2	12KV/125A/3600A	
	CB-3	12KV/125A/3600A	
	CB-4	12KV/125A/3600A	
Isolators Switches	SW-1	33KV/630A	
	SW-2	33KV/630A	
	SW-3	33KV/630A	
	SW-4	33KV/630A	
Current Transformer	CT-1	Primary	Secondary
		262A	262A
Feeders	Load-1	1250A	
	Load-2	1250A	
	Load-3	1250A	
	Load-4	1250A	

Source: PHEDC

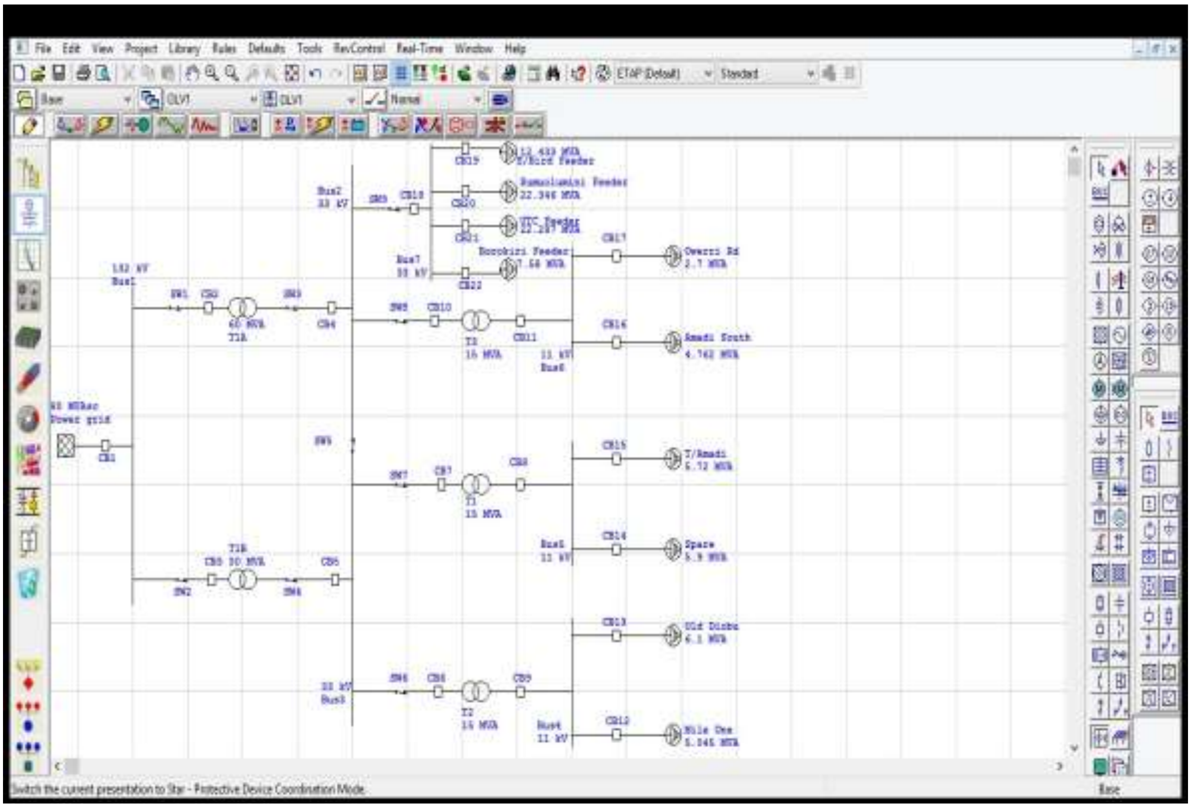

Figure 3.1: 33/11KV Injection Substation at Zone 4, Nzimiro Old GRA, Port-Harcourt

3.2 Method of Analysis

Having modeled the existing case study (as a representation of the activities on the system network), the data collected were used to calculate the impedance, admittances, etc.

Short-circuit analysis technique were adopted to investigate the activities of relay-circuit breaker action. The technique will be used to run the simulation of the modeled network of the existing case, Zone-4 (2 X 15 MVA, 33/11KV injection station), owing to the data gathered from the relevant equations.

The resistance of a conductor is given as: $R = \rho \frac{l}{A} (\Omega)$

Where:

R: Resistance of the conductor (Ω)

ℓ: Resistivity of conductor at a given temperature in (Ω/m)

l: length of conductor in (m)

A: Conductor cross-sectional area (A) is given as: $A = \frac{\pi d^2}{4}$

Diameter, d = 2r

Per kilometer reactance of one phase can be evaluated as:

$$x_0 = 0.144\log_{10}\left(\frac{D_{GMD}}{r}\right) + 0.0157$$

Where:

D_{GMD} : the geometric mean distance between the line conductors

r: is taken as radius of conductors

If a 3-phase fault occur on the 11KV at Injection Substation,

$$\text{Fault MVA} = \frac{\text{Base MVA}}{\text{Total fault impedance at Nzimiro Injection Substation}}$$

At Injection Substation, fault current can be determined as:

$$\text{Fault current} = \frac{\text{Fault MVA X } 10^3}{\sqrt{3}V_L}$$

where: V_L = Line voltage

3.3.1 Calculation of Transformer Full Load Current

For Case 1: Calculation of Transformer Full Load Current for Amadi-South Feeder

$I = \frac{P}{\sqrt{3}V_L}$, Amadi-South feeder has 4.762 MVA

$\frac{4.762 \text{ X } 10^6}{\sqrt{3}\text{X } 11\text{X } 10^3} = \frac{4.762\text{X } 10^3}{\sqrt{3}\text{X } 11} = \frac{4.762\text{X } 10^3}{19.053} = 249.93$ A

For Case 2: Calculation of Transformer Full Load Current for Mile One Feeder

$I = \frac{P}{\sqrt{3}V_L}$, Mile One feeder has 5.045 MVA

$\frac{5.045 \text{ X } 10^6}{\sqrt{3}\text{X } 11\text{X } 10^3} = \frac{5.045 \text{ X } 10^3}{\sqrt{3}\text{X } 11} = \frac{5.045 \text{ X } 10^3}{19.053} = 264.79$ A

3.3.2 Calculation of Fault MVA and Fault Current

Fault MVA = $\frac{\text{Base MVA}}{\text{pu } X_{\text{equivalent}} \text{ MVA}}$ and Fault current = $\frac{\text{Fault MVA X } 10^3}{\sqrt{3}V_L}$

Calculation of Fault MVA and Fault Current for Transformer T1

The following information are provided for transformer T1;

Base MVA= 15KVA, 11 KV, reactance = 10 %

Fault MVA = $\frac{15{,}000 \text{ X } 10^{-3}}{\frac{10}{100}} = \frac{15}{0.1} = 150$ MVA

Fault current = $\frac{150 \text{ X } 10^3}{\sqrt{3} \text{ X } 11\text{X}10^3} = 7.873$ A

IV. RESULTS AND DISCUSSION

4.1 Presentation of Results with the Penetration of Differential Relay Protection

The application of universal matching C.Ts was used such that the right ratio and connections are selected in a manner that individual auxiliary C.Ts for every discrete application of transformers differential protection of various voltage values and vector groups is eliminated. The differential protection principle is considered as a unit protection with its zone constrained by location of current transformers (CTs) with respect to selectivity, sensitivity, and speed of operation when compared with directional comparison, phase comparison, or stepped distance schemes.

However, there are two common types of differential relaying exist, namely the current differential relaying and voltage differential relaying. The current differential relaying play a very vital role in the protection system and is also known as the current balance method or circulating current method of differential relay protection. Different differential relay applications fall in the group of current differential method and the method is applied for the protection of transformers, motors, generators and bus bars. Similarly, the voltage differential relaying is also known as voltage balance method or opposed voltage relay protection. Consequently, the plants are installed to improve the voltage stability in the grid during and following major network disturbances.

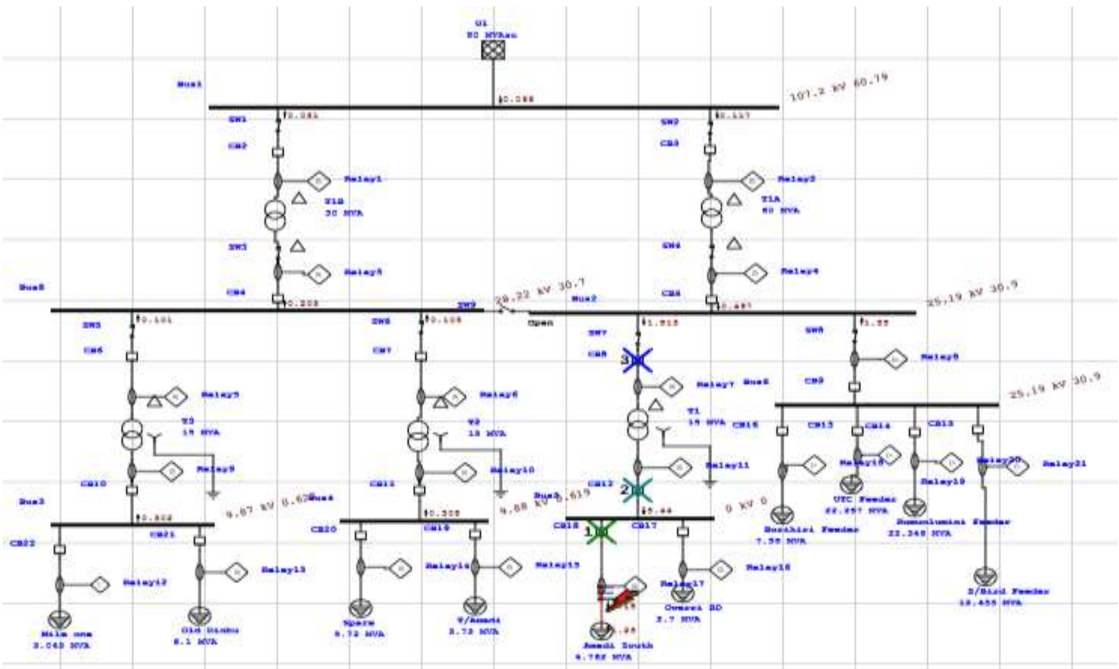

Figure 4.1: Presentation of Simulated Single Line Diagram Showing Fault on Amadi South 11KV Feeder

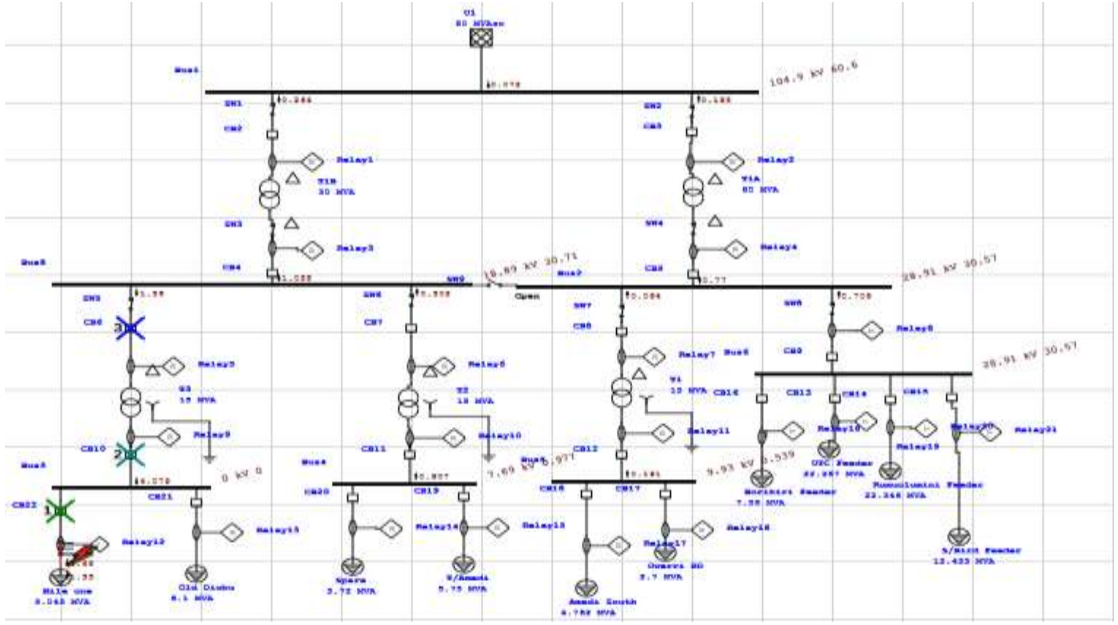

Figure 4.2: Presentation of Simulated Single Line Diagram Showing Fault on Mile One 11KV Feeder

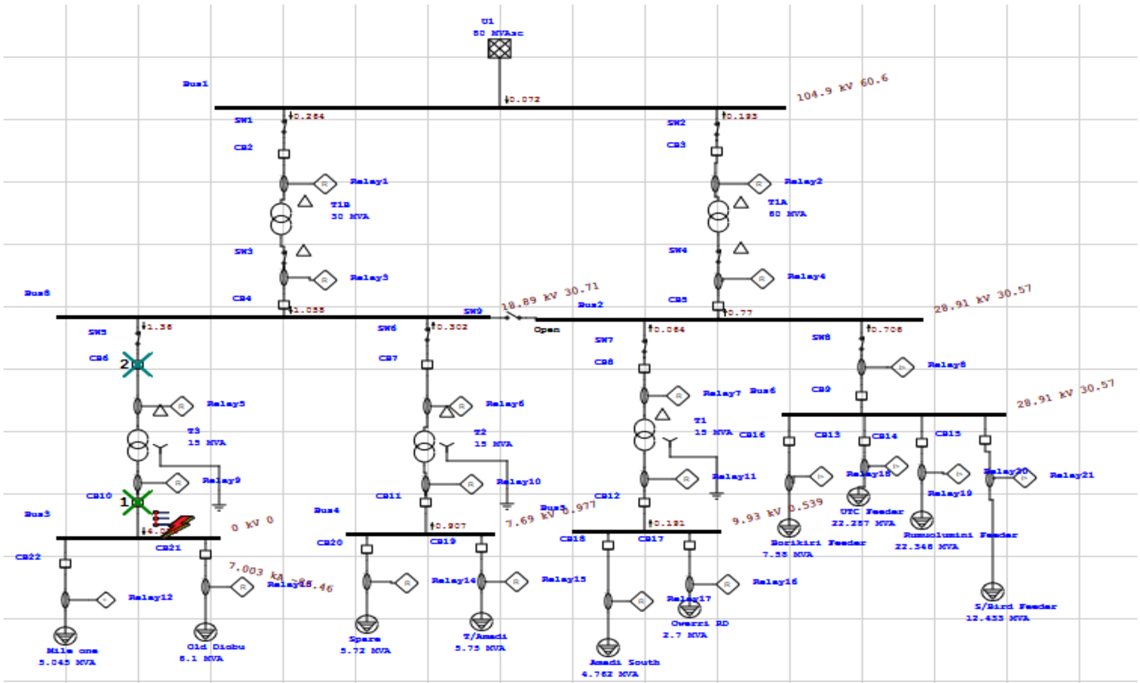

Figure 4.3: Presentation of Simulated Single Line Diagram Showing Fault on Transformer T1 11KV Incomer

Table 4.1: Symmetrical 3-phase Faults

Time (ms)	ID	If(kA)	T1(ms)	Condition
0.4	Relay 1	0.075	< 0.4	Overload Acceleration
0.4	Relay 2	0.151	< 0.4	Overload Acceleration
0.4	Relay 4	0.604	< 0.4	Overload Acceleration
0.4	Relay 5	0.302	< 0.4	Overload Acceleration
0.4	Relay 6	0.182	< 0.4	Overload Acceleration
0.4	Relay 9	1.055	< 0.4	Overload Acceleration
0.4	Relay 10	0.384	< 0.4	Overload Acceleration
0.4	Relay 12	0.546	< 0.4	Overload Acceleration
5.0	Relay 3	0.226	5.0	Overload Acceleration
10.0	Relay 1	0.075	10.0	Phase-OCI-51
10.0	Relay 2	0.151	10.0	Phase-OCI-51
10.0	Relay 4	0.604	10.0	Phase-OCI-51

10.0	Relay 5	0.302	10.0	Phase-OCI-51
10.0	Relay 6	0.182	10.0	Phase-OCI-51
10.0	Relay 9	1.055	10.0	Phase-OCI-51
10.0	Relay 10	0.384	10.0	Phase-OCI-51
10.0	Relay 12	0.546	10.0	Phase-OCI-51
15.0	Relay 2	0.151	15.0	Phase-OCI-50
15.0	Relay 4	0.604	15.0	Phase-OCI-50
15.0	Relay 5	0.302	15.0	Phase-OCI-50
15.0	Relay 6	0.182	15.0	Phase-OCI-50
15.0	Relay 9	1.055	15.0	Phase-OCI-50
15.0	Relay 10	0.384	15.0	Phase-OCI-50
15.0	Relay 12	0.546	15.0	Phase-OCI-50
40.0	Relay 1	0.075	40.0	Jam
40.0	Relay 2	0.151	40.0	Jam
40.0	Relay 3	0.226	40.0	Jam
40.0	Relay 4	0.604	40.0	Jam
40.0	Relay 5	0.302	40.0	Jam
40.0	Relay 6	0.182	40.0	Jam
40.0	Relay 9	1.055	40.0	Jam
40.0	Relay 10	0.384	40.0	Jam
40.0	Relay 12	0.56	40.0	Jam
55.4	CB1		55.0	Tripped by Relay 10 Overload Acceleration

The table indicate the Symmetrical 3-phase Faults showing the time where the relay tripped at various time interval with the conditions and the fault currents.

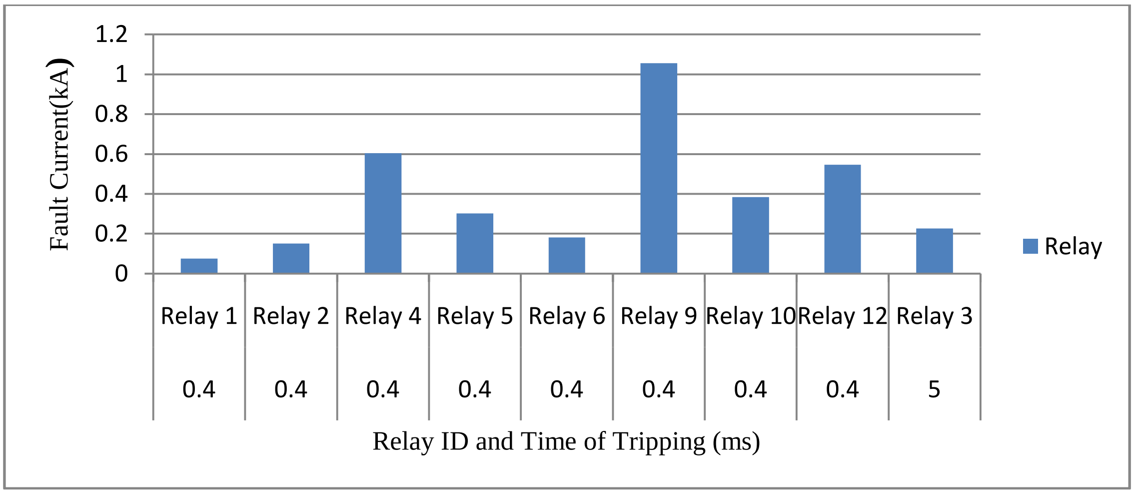

Figure 4.4: A Bar Chart of Symmetrical 3-Phase Faults of Relay ID and Time of Tripping at 0.4 (ms) with Faults Current

The above figure show the symmetrical 3-phase faults of each relays and the time of tripping at 0.4 (ms) with the fault current (kA). This indicate that at given time interval, relay 3 failed to trip the CB when fault was introduced close to it at 5 (ms). In the other hand relays 1, 2, 4, 5, 6,10 and 12 tripped their associated CBs when fault was introduced close to each of them. But relay 9 has the highest fault current of 1.055 (kA). Each condition was indicated to overload acceleration.

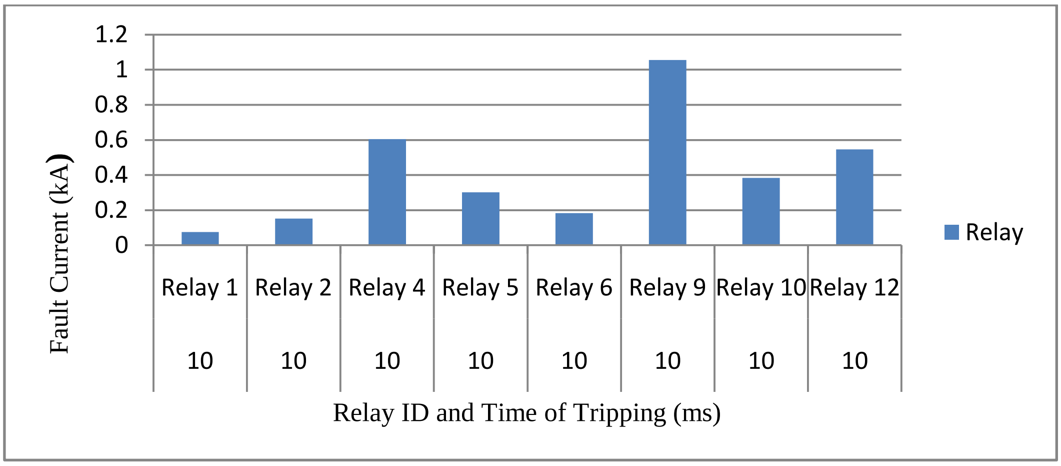

Figure 4.5: A Bar Chart of Symmetrical 3-Phase Faults of Relay ID and Time of Tripping at 10 (ms) with Faults Current

The above figure show the symmetrical 3-phase faults of each relays and the time of tripping at 10 (ms) with the fault current (kA). This indicate that at given time interval relays 1, 2, 4, 5, 6,10 and 12 tripped their associated CBs when fault was introduced close to each of them. But relay 9 has the highest fault current of 1.055 (kA). Each condition was indicated to Overload Acceleration.

4.6 Analysis from Verification of Relays Sensitivity Result (Case Study 1)

The result obtained from the short circuit analysis using the available CTRs on 33/11KV injection substation at Nzimiro, Port Harcourt zone 4, Old GRA networks shows that:

i. T1 failed to trip the CB when fault was introduced close to it.
ii. T2 failed to trip the CB when fault was introduced close to it.
iii. T3 failed to trip the CB when fault was introduced close to it.
iv. All other relays tripped their associated CBs when fault was introduced close to each of them.

4.7 Analysis from Verification of Relays Sensitivity Result (Case Study 2)

The result obtained from the short circuit analysis using the available CTRs on 33/11KV injection substation at Nzimiro, Port Harcourt zone 4, Old GRA networks shows that:

i. T1 tripped the CB when fault was introduced close to it.
ii. T2 tripped the CB when fault was introduced close to it.
iii. T3 tripped the CB when fault was introduced close to it.
iv. All other relays tripped their associated CBs when fault was introduced close to each of them.

4.8 Transformers Differential Protection Result

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

Table 4.2 Transformer Differential Protection

Case	Primary CTRs	Secondary CTRs	Matching CT	Status
Case 1	600/5	1200/5	4.374A/6.561A	Mismatch
Case 2	600/5	1800/5	6.561A/6.560A	Match

It was noted that CT mismatch occurred while conducting a well guided manual calculation on the differential protection of the 30MVA and 45MVA transformers respectively. However, correct CT matching was achieved after interchanging the present CTR of 1800/5 with another CTR of 600/5.

Moreover, both 11KV incomer relays failed to operate when fault occurred very close to them until the CTR of 1800/5 for each was replaced with that of 600/5 the relays operated accordingly.

V. CONCLUSION AND RECOMMENDATIONS

The data collected were used to conduct well guided manual calculation to verify and further improve on as may be required the analysis of differential protection for transformers type, analysis from verification of relays sensitivity result, transformers differential protection, and relays sensitivity verification result. Also, the use of Electrical Transient Analyser Programme (ETAP) version 12.6 was used to ascertain and improve the relays operations at 33/11KV Injection substation at Zone 4, Nzimiro, Old GRA Port Harcourt.

The result of the transformers differential protection shows that the CT mismatch occurred, and there was a wide gap between the secondary CT secondary line current of 4.374A and primary CT secondary line current of 6.561A.

Furthermore, the replacement of CTR on the transformer secondary automatically closed the wide gap, and matching CT was obtained with the value as 6.561A/6.560A. Similarly, all the relays operated when fault was introduced thereby leaving two (2) relays out. Nevertheless, the transformer secondary relays failed to operate at the introduction of fault. Conversely, the CT value of 600/5 was replaced with 1800/5 and the relays operated accordingly.

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ABOUT THE AUTHORS

Kanikwu, Ibietela Wariboko holds a B.Tech in Electrical Engineering (power option), Department of Electrical Engineering, Rivers State University. Currently at the peak of Master's Degree, Rivers State University Port Harcourt, Rivers State, Nigeria.

Idoniboyeobu, Dikio Clifford is a Professor in the Department of Electrical Engineering, Rivers State University, Port Harcourt. He holds B.Eng degree in Electrical Engineering, Ahmadu Bello University, Zaria; M.Sc and Ph.D degrees in Electrical Engineering, University of Manchester, UK. He is COREN registered and a member of several Professional Organizations.

Braide, Sepiribo Lucky holds B.Tech in Electrical Engineering, M.Tech Electrical Engineering, Department of Electrical Engineering, Rivers State University Port Harcourt and Ph.D Electrical Engineering, Federal Technology Owerri and he is COREN registered and member of several professional organizations.=

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