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MATLAB Simulation of Protection Scheme for 15MVA 33/11kv Marine Base Injection Substation Power Distribution Network using Differential Relay 87

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ABSTRACT
Electrical energy is the basic necessity for the economic development of a country due to its importance to human life and occupies the top position in the energy hierarchy. Just as no human being can survive without the flow of blood, no nation or city can develop without reliable electricity. MATLAB/Simulink software is to be use in the designing and simulation of the protection scheme for the Marine base injection substation 33/11kv power distribution network. This paper presents the differential relay (87) as sensing device in the protection scheme; which uses the differential current approach between the current passing through the secondary side of the current transformers $(i_1 \text{ and } i_2)$. To offer protection to the power network the sensing device; detects changes in the electrical parameters and initiates a tripping signal to the circuit breaker for operation. Measure differential current, restraint current, and relay tripping signals, through iterative simulations, adjustments to k, I_{bias} , and CT settings can optimize the protection scheme, enhancing its ability to differentiate between internal and external faults and improving its performance for the Marine Base Injection Substation.
Keywords: Differential Relay (87), Electric Energy, MATLAB/Simulink, Power Network, Sensing Device

INTRODUCTION
Electrical energy is the basic necessity for the economic development of a country due to its importance to human life and occupies the top position in the energy hierarchy. It finds innumerable uses in the home, industry, agriculture, and transport. The demand for electrical power is generally in the increase at a fast rate in economically developing countries like Nigeria. So, the power distribution networks are becoming highly loaded; so, the issue of protection scheme has become a great concern in most of the injection substation power distribution networks. A number of works have been carried out in the area of electric power distribution protection and solutions have been proposed to improve the protection of the distribution network (Ijeoma and Amadi, 2024).
Reliable energy technologies are expected to play a major role in mitigating pressing societal challenges such as climate change and resource depletion, while contributing to domestic energy security. Just as no human being can survive without the flow of blood, no nation or city can develop without reliable electricity. The developed nations rode on reliable electricity to attain and sustain their present status. Today, they can boast of years of uninterrupted power supply which have helped their industries, utilities, hospitals, schools, etc to make life comfortable for their citizens. This means

that, we can comfortably say that no nation can move from an underdeveloped status to becoming a developed nation without reliable electricity; no reliable electricity, no development. Sustainable developments have continued to elude Nigeria as a nation due to lack of reliable electricity (Ibinabo and Ijeoma, 2019).

A Sub-Cycle phase angle distance measure algorithm for power transformer differential protection. The recommended approach is based on the assumption that a fault signal's fundamental phase angle should ideally remain constant throughout the error. Nevertheless, under inrush circumstances, the phase angle is altered. Furthermore, when there is an intrinsic fault, the current signals from the CT have phase angles that match; when there is an exterior fault, they are 180 degrees out of phase. The suggested method first computes the sub-cycle modified recursive least squares (MRLS) basic phase angles of the CTs current signals. Next, normalized mean residue (NMR) is used to calculate the CT's currents estimated phase angles for distance. For the MRLS and NMR algorithms to do their calculations, a limited number of samples (10 and 5 samples, respectively) are required. The demonstration evaluation of the suggested strategy shows its ability to distinguish between internal defect currents and both an outward failure and an inrush-currents utilizing recorded current signals from experiments and simulations (Tajdinian et al. 2022).

Transformer power differential protection using real-time HIL test-based implementation of second-order transient-extracting transform. The recommended approach depends on the wave-shape characteristics of the power signal in real time. Second-order Transient-Extracting transform (STET), a high-resolution time-frequency analysis (TFA) technique, is used to achieve discriminating. Furthermore, to assess how quickly the suggested method, the outcomes of a Raspberry Pi (R-Pi) is used in a Hardware-in-the-Loop (HIL) test to investigate the STET approach. This actual time modification results in the determination of the internal issue as well as additional transient phenomenal distinguishing time to be 14ms. The suggested approach is completely noise-immune and does not require transformer specifications or different power system operating circumstances. The suggested method's usefulness is assessed using both experimental and multiple simulation runs. To make sure the suggested approach is feasible, two experimental configurations are taken into consideration. The first is a lab setup designed to record inrush current and internal fault waveforms from genuine transformers. The Vebko Amirkabir AMT105 relay tester, together with a relay and CT tester, are included in the second one. The laboratory CT is used to determine the C A Multiagent System-Based Protection and Control Scheme for Distribution System, With Distributed-Generation Integration." A multi-agent system for defense and management technique was presented in this work to address the different operating conditions in distribution systems caused by distributed-generation (DG) integration. For converter-based wind turbine DG, an adaptive protection and control algorithm is developed based on relay and DG controller collaboration to reduce the impact of in-feed fault current. Protective relays can be made to adapt to varying operating conditions resulting from changes in system topology and DG status by using an adaptive relay configuration technique that takes into account DG control modes. In a hardware-in-the-loop real-time testing environment, the suggested method is verified and examined using a test distribution system. (Liu et al. 2017)T saturation test (Hosseini-Biyouki and Askarian-Abyaneh, 2022).

A New method for differential protection in Power transformer, a transformer protection plan based on the Clark transformation design is provided in this study. It increases the sensitivity with which the power transformer protection system's digital differential relay distinguishes between inrush current and fault current. A variety of test activities have been utilized in MATLAB/SIMULINK to mimic the suggested technique (Kainth and Sharma, 2014). Dynamic Adaptive Protection for Distribution Systems in Grid-Connected and Islanded Modes, this study proposes a dynamic AOCR technique for relay pickup estimate that is independent of external controllers, ensuring substantially less communication overhead. With the assistance of the proposed plan, state-of-the-art challenges are addressed and managed in the present and future. Using Simulink's transient system models, the dependability of a 15-bus distribution system is investigated for all possible states, failure types, and impedance combinations (Jain et al. 2019).

Dynamic Differential Current-Based Transformer Protection Using Convolution Neural Network, by combining the pre- and post-disturbance differential currents in real time, this study provides a dynamic differential current that makes it possible to create transformer protection based on this dynamic differential current. The feature adjustments of the differential current are thus the main emphasis (Li et al. 2022).

Reliability Assessment of Distribution System through Cost Analysis, this paper provides a comprehensive examination considering the dependability of the 11kV Karberey-Ramety Feeder-II electrical power distribution system assessment and future application enhancements. The primary goal of the research is to use Failure Mode and Effect Analysis to ascertain the reliability of the distribution system. It also offers a comprehensive economic study to determine the optimal number and location of automatic switches that satisfy reliability and cost criteria (Puri et al. 2020).

Power distribution system fault monitoring device for supply networks in Nigeria, in order to detect and alert when the building's incomer line encounters a change in phase, high and low voltages, over-current, or melt fuse, the primary objective of this project is to create a gadget for monitoring the electrical grid on-site that will be put on specific household entrance power cables. The fault indicator will help reduce troubleshooting duration and guarantee a prompt recuperation of service. Test results confirm the device's functionality, the design's accuracy, and its applicability as a reasonably priced solution for monitoring power supply system failure in nearby towns (Kareem et al. 2019).

Simulink model of transformer differential protection using phase angle difference-based algorithm, this study presents the implementation of a % differential relay-based phase-angle-difference technique. The algorithm will be used to stop the transformer differential relay when a magnetizing inrush current is applied. In this study, Simu-link and MATLAB are used to model and implement the approach. The simulation model is the actual circuit model for the power and current transformers. The outcomes confirmed the technique's efficacy in many operating modes, including internal transformer faults, magnetizing inrush currents, and current transformer saturation (Iqteit & Yahya, 2020).

Design and Fabrication of All-in-One Protective Relay for Distribution Transformer, their project's core purpose is to protect the distribution transformer, for which we are creating an all-in-one relay. Transformers are susceptible to two types of defects: system-damaging external faults like high voltage spikes or short circuits, and interior faults such insulation failure. Internal issues arise in the transformer zone. Thus, the only defects that are highlighted are internal ones since, if ignored, they could have fatal consequences. Distinctive protection strategy is one efficient way to find errors. Utilizing the differential relay operating principle, they are creating an all-in-one relay. PROTEUS 8 PROFESSIONAL is used for designing relay circuits, while MATLAB and SIMULINK are used for fault analysis. By fault analysis, three essential relay features were identified: selective, quick, and sensitive. A numbered relay is what we will call a single relay in this instance. In order to really operate the relay, numerical relays require an additional component: software that runs in the background. One way to distinguish one numerical relay from another is with the aid of software (Gupta et al. 2016).

In order to minimize the interruption to the remaining parts of the electric system, the protection scheme's principal goal is to promptly identify and isolate any malfunctioning or defective components. That means that the protection method should be rapid when needed, selective (i.e., only the system's faulty section(s) should be isolated), secure (not operate unnecessarily), and dependable. The protection method would be essentially ineffective and might potentially cause issues for the power system in the absence of these fundamental needs (Obied & Abdul-Wahhab, 2021).

In a distribution network, protective relays are used to identify anomalies in the network and promptly isolate the problematic portion from the remainder of the system. An electrical power outage is caused by damage from lightning strikes and other network errors. Longer overhead wires have a higher chance of developing faults since they are exposed to more air conditions. The distribution network can be secured in a variety of ways. Transformers connect the networks for distribution and transmission. Transformers scale down the voltages to link the higher-level transmission network to the lower level distribution networks (Azizan et al. 2020).

MATERIALS AND METHOD

Materials Used

MATLAB/Simulink software is to be use in the designing and simulation of the protection scheme for the Marine base injection substation 33/11kv power distribution network.

This paper presents the differential relay (87) as sensing device in the protection scheme; which uses the differential current approach between the current passing through the secondary side of the current transformers $(i_1 \text{ and } i_2)$. To offer protection to the power network the sensing device; detects changes in the electrical parameters and initiates a tripping signal to the circuit breaker for operation.

Method

Mathematical model for the improvement and simulation of the differential protection scheme in a 15 MVA, 33/11 kV Marine Base Injection Substation, we will delve deeper into the following areas:

1. System Parameters and Per-Unit Modeling
2. Differential Protection Equations
3. Fault Condition Analysis
4. Current Transformer Modeling and Effects
5. Relay Operating Characteristics and Protection Settings
6. Simulation Setup for Fault Scenarios

1. System Parameters and Per-Unit Modeling

Per-unit (p.u.) system modelling simplifies the calculation of electrical quantities in power systems by normalizing values relative to a base power and voltage.

For a transformer with:

- **Power Base** S_{base} = 15 MVA
- **Primary Voltage Base** V_{base}, Primary = 33kv
- **Secondary Voltage Base** V_{base}, Secondary = 11kv

The per-unit impedance Z_{pu} can be calculated as:

$$Z_{pu} = \frac{Z_{actual}}{Z_{base}}$$

Transformer Impedance Calculation:

Given impedance $Z_{transformer}$ = r+jx (in actual ohms), its per-unit representation is:

$$Z_{pu,\ transfomer} = \frac{r + jx}{\frac{V^2_{base,\ primary}}{S_{base}}}$$

Using this base, all voltages, currents, and impedances in the network can be normalized.

2. Differential Protection Equations

The core of differential protection is to detect a difference in current between the transformer's primary and secondary sides.

(a) Primary and Secondary Currents (CT Ratios)

Define:

- $I_{primary}$: Current on the 33 kV
- $I_{secondary}$: Current on the 11 kV, adjusted by CT ratios

If the current transformers (CTs) on the primary and secondary sides have ratios of $CT_{primary}$ and $CT_{secondary}$ respectively, then:

$$I_{primary,\ CT} = \frac{I_{Primary}}{CT_{primary}}$$

(b) Differential and Restraint Currents

The Differential Current I_{diff} is defined as:

I_{diff} = [$I_{primary,\ CT}$- $I_{secondary,\ CT}$]

The Restraint Current I_{res} is calculated as:

$$I_{res} = \frac{[I_{primary,\ CT}] + [I_{secondary,\ CT}]}{2}$$

(c) Relay Operating Condition
The relay operates when:

$$I_{diff} \geq k.I_{res} + I_{bias}$$

Where: k is a slope setting that compensates for external fault conditions and
I_{bias} is the minimum threshold to prevent relay operation for small imbalances or transient conditions.

3. Fault Condition Analysis
Differential protection is designed to respond to internal faults (inside the transformer) and ignore external faults (outside the transformer). This requires modeling various fault conditions:
(a) Internal Faults: Examples include
Phase-to-phase faults within the transformer
Phase-to-ground faults within the transformer
For internal faults, the differential current I_{diff} will be significant as the current entering the transformer will differ from the current leaving.
(b) External Faults: These faults occur outside the transformer, typically in feeders or adjacent substations, and ideally should not trigger the relay. Here, both $I_{primary}$ and $I_{secondary}$ should be nearly equal (considering CT accuracy), keeping I_{diff} low.

4. Current Transformer Modeling and Effects
CTs are critical for providing accurate current measurements to the relay. However, CT saturation can affect measurement, especially under high fault conditions.
(a) CT Saturation Effect
When CTs saturate:

$$I_{primary,\ CT} \neq I_{primary,\ actual}$$

To model CT saturation, the saturation characteristic of the CT should be included:
Define a saturation limit current beyond which the CT output is nonlinear.

5. Relay Operating Characteristics and Protection Settings
The slope setting k and minimum pickup current I_{bias} are crucial for determining when the relay operates.
High Slope Setting (k larger): Provides stability for external faults and high inrush currents.
Low Slope Setting: Increases sensitivity, making the relay more responsive to small internal faults.
The optimal values for k and I_{bias} depend on balancing sensitivity and security, which can be evaluated through fault simulation.

6. Simulation Setup for Fault Scenarios
Using MATLAB/Simulink for simulation, we can set up the following:
1. Transformer Model: Include primary and secondary windings, rated impedance, and magnetizing characteristics.
2. Fault Injection: Apply different fault types (internal and external) to observe relay response.
3. Differential Relay Logic: Implement the operating condition equation in the simulation environment.
4. CT Saturation Modeling: Introduce saturation characteristics to observe effects on differential and restraint currents.
Differential Relay in Subsystem of the Simulation Model
Figure 1 shows the configuration of the differential relay in MATLAB/Simulink; with the installment of two in portals In1 and In2.

(i) The two inlet terminals received current signals from CT1 and CT2 respectively.
(ii) In other to study this set up, In1 and In2 signals have to be separated into three parallel paths.
(iii) Every signal will go in to a unit; the first signals goes in to a unit called amplitude comparator.
(iv) The second signals which is stamped under pressure in the harmonic test, and the resultant signals enters the unit called harmonic comparator.

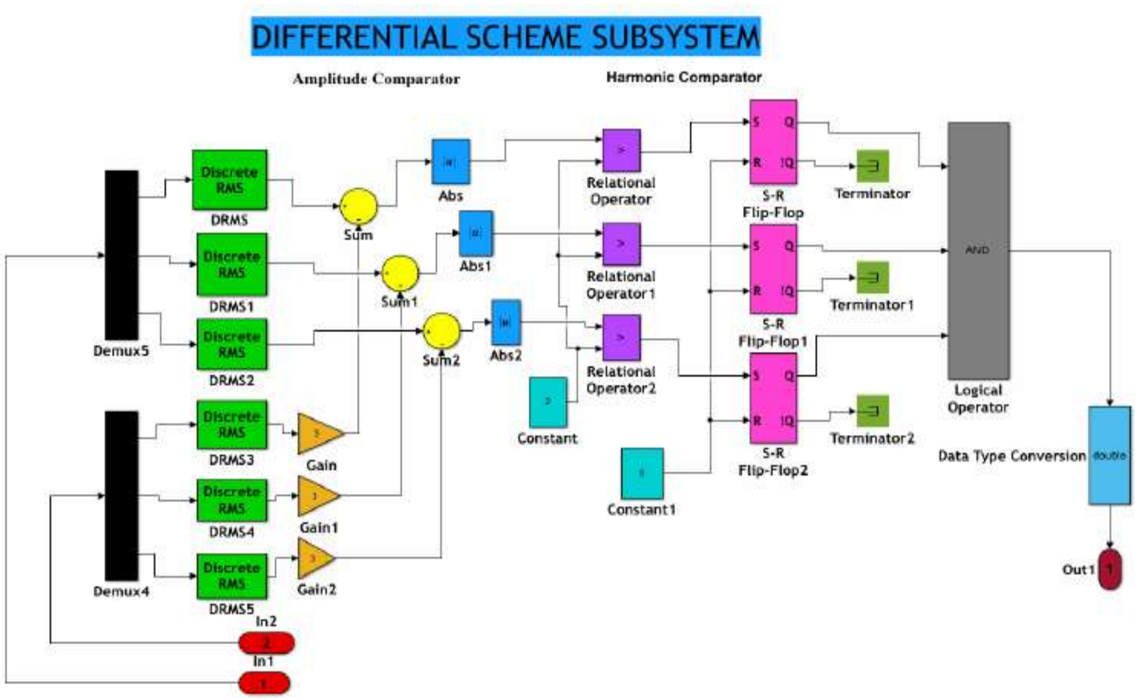

Figure 1: Differential Relaying in Subsystem

The amplitude comparator will compare both input In1 and In2 current amplitudes. Where there is a signal difference between the two signals (In1 and In2), the comparator unit shows the differences; as sent to it by the amplitude comparator. Simultaneously, the subsystem will send two signals to the harmonic comparator unit; which in turn relate it to the comparator. An assessment of the input signal will be made by the subsystem unit; to examine if there is harmonics in the signal.
The unit of the subsystem contents is also explained in Figure 1.

(i) Within the subsystem, there are two inlet entries. The voltage at the first input, which is 33kv, must be balanced by the gain at input two, which is three, because the secondary winding of the transformer has a voltage of 11kv.
(ii) Reducing the secondary side current in the transformer to match the primary side current is the goal of gain 3.
(iii) Relay control is developed based on the digital operating framework.
(iv) To contrast the required inlet current and pickup current, the relational operator is employed.
(v) The connection of the S-R flip flop is to the relational operator's output.

RESULT AND ANALYSIS

Measure differential current, restraint current, and relay tripping signals, through iterative simulations, adjustments to k, I_{bias} , and CT settings can optimize the protection scheme, enhancing its ability to differentiate between internal and external faults and improving its performance for the Marine Base Injection Substation.

Simulation results of L-G fault when fault occurs at point 1

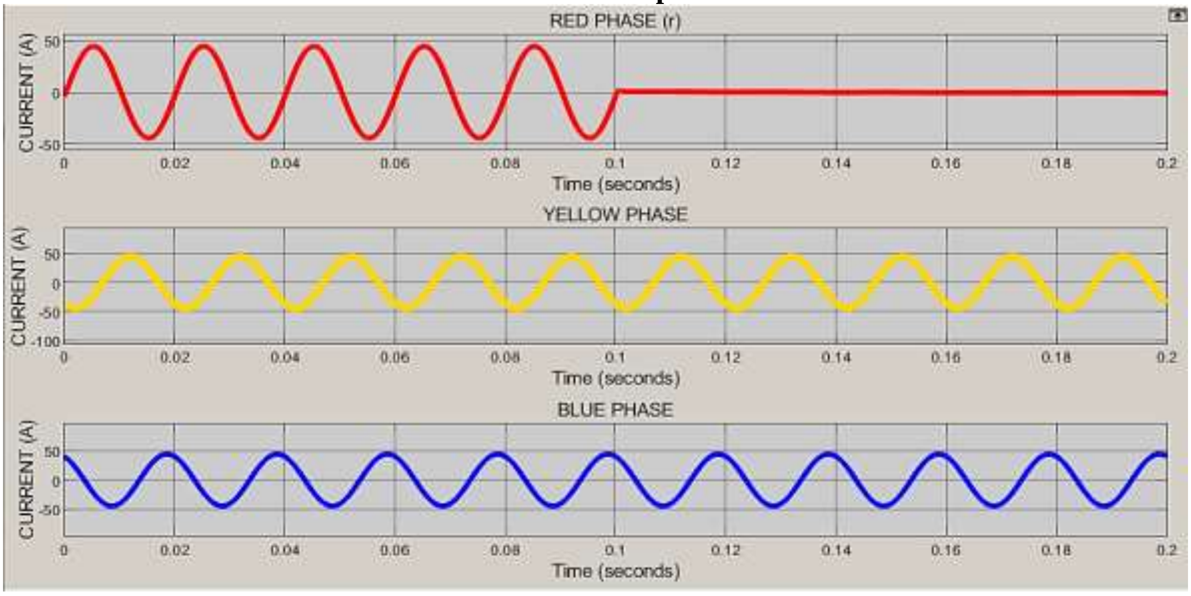

Figure 2: Simulation result on primary side to when fault occurred at point 1 (L-G)

Table 1: Signal Statistics for Simulated results of L-G fault when fault occurs at point 1

Primary side					
Red Phase		Yellow Phase		Blue Phase	
Tripped Time (S)	Fault Current Value (A)	Tripped Time (S)	Load Current Value (A)	Tripped Time (S)	Load Current Value (A)
0.1	23.84	Nil	30.85	Nil	30.43
Secondary side					
Red Phase		Yellow Phase		Blue Phase	
Tripped Time (S)	Fault Current Value (A)	Tripped Time (S)	Load Current Value (A)	Tripped Time (S)	Load Current Value (A)
0.1	69.73	Nil	90.03	Nil	89.22

The L-G simulation results are displayed in figure 1 and table 2; the simulation was run with fault on point 1, and the findings indicate that the L-G fault is an internal fault located inside the protection zone. The circuit breaker tripped at a time of t=0.1s after the relay sensed the variances in currents (i1 and i2) on the line. The protection scheme segregated only the faulted red phase from the rest of the healthy system (grid).

Simulation results of L-G fault when fault occurs at point 2

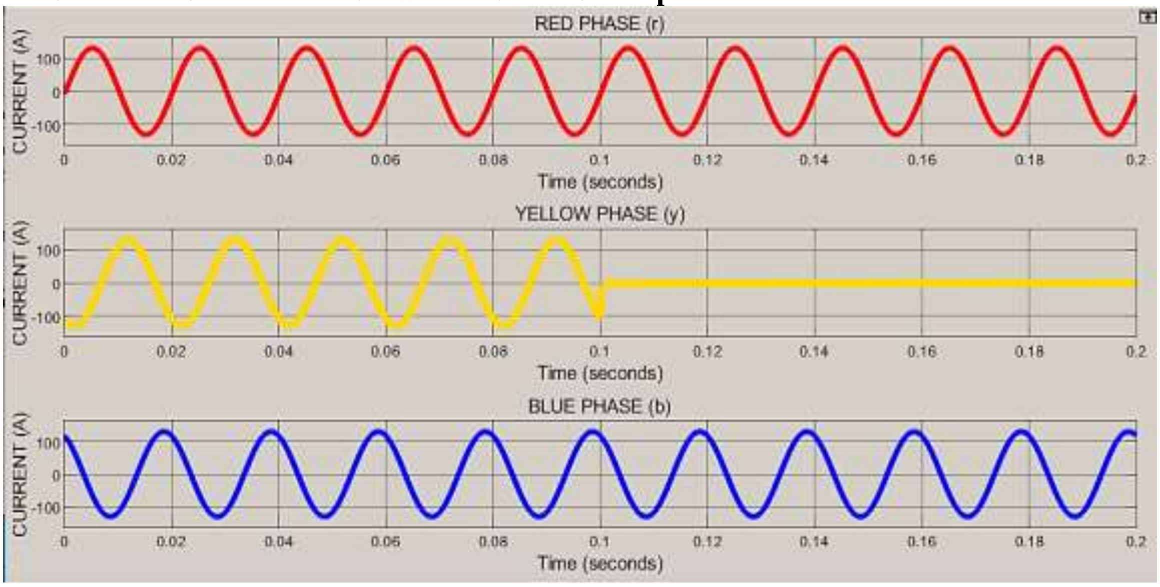

Figure 3: Simulation result on secondary side when fault occurred at point 2 (L-G)

Table 2: Signal Statistics for Simulated results of L-G fault when fault occurs at point 2

Primary side					
Red Phase		Yellow Phase		Blue Phase	
Tripped Time (S)	Load Current Value (A)	Tripped Time (S)	Fault Current Value (A)	Tripped Time (S)	Load Current Value (A)
Nil	31.30	0.1	1118	Nil	31.80
Secondary side					
Red Phase		Yellow Phase		Blue Phase	
Tripped Time (S)	Load Current Value (A)	Tripped Time (S)	Fault Current Value (A)	Tripped Time (S)	Load Current Value (A)
Nil	91.55	0.1	70.13	Nil	93.03

The findings of the L-G simulation, which was run on point 2, are displayed in figure 3 and table 2; the simulation indicates that the L-G fault on point 2 is also an internal fault located inside the protection zone. The circuit breaker tripped at a time of t=0.1s after the relay sensed the variances in currents (i_1 and i_2) on the line; only the yellow phase at the secondary was isolated from the remaining healthy system (load side).

Simulation results of L-G fault when fault occurs at point 3

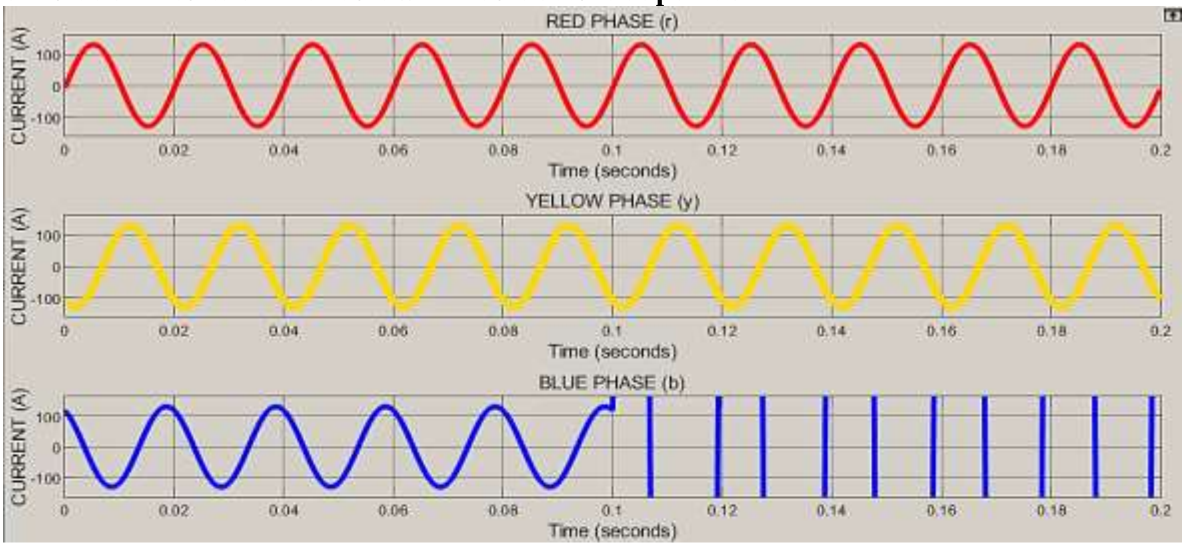

Figure 3: simulation result on secondary side when fault occurred at point 3 (L-G)

Table 3: Signal Statistics for Simulated results of L-G fault when fault occurs at point 3

Primary side					
Red Phase		Yellow Phase		Blue Phase	
Tripped Time (S)	Load Current Value (A)	Tripped Time (S)	Load Current Value (A)	Tripped Time (S)	Fault Current Value (A)
Nil	30.86	Nil	31.28	Nil	963.4
Secondary side					
Red Phase		Yellow Phase		Blue Phase	
Tripped Time (S)	Load Current Value (A)	Tripped Time (S)	Load Current Value (A)	Tripped Time (S)	Fault Current Value (A)
Nil	90.23	Nil	91.64	Nil	2890

The result of an external L-G fault on the blue phase at point 3 is displayed in figures 3 and table 3. Because the fault lies outside of the differential relay's protection zone and the fault current travels through the blue phase's CTs rather than the relay, the relay could not detect the fault current so as to trip the circuit breaker. The transformer's current fluctuates, but since this is referred to as an external problem, the differential relay did not respond to it.

From the table 4; the simulation tests are shown, the tests were carried out in both internal and external fault conditions in different phases; all faults located inside the protection zone (points 1 and 2); the relays have reacted precisely without error, whenever it identifies or locate a fault. In all the faults that occurred at point 3, the relays never reacted as they are considered as an external fault.

Table 4: Analysis of Simulated Faults

Type of faults	Point of fault	Relay/Circuit breaker operation	Protection Zone	Fault Condition
3-Phase to Ground Fault L-L-L-G	Point 1	Tripped	Inside	Internal
	Point 2	Tripped	Inside	Internal
	Point 3	No Tripping	Outside	External
2-Phase to Ground Fault L-L-G	Point 1	Tripped	Inside	Internal
	Point 2	Tripped	Inside	Internal
	Point 3	No Tripping	Outside	External
2-Phase Fault L-L	Point 1	Tripped	Inside	Internal
	Point 2	Tripped	Inside	Internal
	Point 3	No Tripping	Outside	External
Single-Phase to Ground Fault L-G	Point 1	Tripped	Inside	Internal
	Point 2	Tripped	Inside	Internal
	Point 3	No Tripping	Outside	External

CONCLUSION

Electrical energy is the basic necessity for the economic development of a country due to its importance to human life and occupies the top position in the energy hierarchy. It finds innumerable uses in the home, industry, agriculture, and transport. The demand for electrical power is generally in the increase at a fast rate in economically developing countries like Nigeria. Figure 1 shows the configuration of the differential relay in MATLAB/Simulink; with the installment of two in portals In1 and In2.

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