Available online www.ejaet.com

European Journal of Advances in Engineering and Technology, 2024, 11(11):33-40

Research Article ISSN: 2394 - 658X

Analysis of Protection Scheme for 15MVA 33/11kv Marine Base Injection Substation Power Distribution Network using Differential Relays

Hachimenum N. Amadi, Erepamo Alfred Ouserigha, Richeal Chinaeche Ijeoma

Electrical Engineering Department, Rivers State University, Nkpolu - Oroworukwo Port - Harcourt, Nigeria
hachimenum.amadi@ust.edu.ng, erepaski@yahoo.co.uk, ijeoma.richeal@ust.edu.ng

ABSTRACT

Electric power systems are made up of equipment from generation, transmission and distribution of electrical energy. The unavoidable fact is that in power systems faults will always occur. Electrical faults cause's strain on all these equipment; and when left un-control or checked, these faults will immediately render this equipment useless which result to the power systems mal-functional. The differential current method is being utilized in this study; it's a protection technique designed to identify flaws within a designated zone. By comparing the currents entering and exiting that zone, it operates. Internal faults on all three phases are depicted in figure 4.3; the secondary side of the transformer is faulted at point 2 (figure 3.3), where the relay triggered a tripping signal that caused all three phases on the secondary side circuit breakers to open at a time of t=0.1s. Despite this, the transformer is not isolated from the grid. MATLAB/Simulink was used to set up and simulate the differential relay scheme; simulations was carried out on different short-circuit faults, on three locations. Such faults were: three-line to ground (L-L-L-G), double-line to ground (L-L-G), single-line to ground (L-G) and line-line (L-L) faults. The results achieved from the simulation test of the scheme; shows that the relay has a restraint current of $0.4647A$ with a tripping time of 0.1s; faster than that of the microcontroller with a tripping time of 0.6s having the same fault current and a station load of about 6.5MW. The scheme is highly sensitive; which enables it to detect minor system faults; it distinguishes between the network's internal and external flaws; also, has been able to detect inrush currents, which enables it to differentiate between transformer inrush currents and fault currents more effectively.

Keywords: Electrical Faults, Electric Power Systems, MATLAB/Simulink, Relay Triggered, Microcontroller

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 [1].

Electric power systems are made up of equipment from generation, transmission, to distribution of electrical energy. Power systems are most times a complex and expensive systems made. The unavoidable fact is that in power systems faults will always occur. Electrical faults cause's strain on all these equipment; and when left un-control or checked, these faults will immediately render this equipment useless which result to the power systems dis-functional. With all these clear facts, there is a need for an auxiliary system which will provide a protection for this equipment within the power system, from faults and abnormal operations [2].

Protection systems are made up of system equipment; protection schemes and policies to spot abnormalities within the system and to carry out measures to correct the situation. The protection systems for electricity generation via transmission up to distribution mainly involved the circuit breakers (CBs for making and breaking of circuit), current transformers (CTs, for reduction of current magnitude), and protective relays (for sensing the difference in current and send tripping signal to the CB for operation). The circuit breakers are responsible for the disconnection and reconnection of the electrical power circuit; the current transformer provide an accurately safe level of the current for relay to handle. The protective relays make use of this safe level current with the help of an inner logic to control the circuit breakers operations. In a normal power system activity the protection system is not required; but it is much more required when the condition of the power system operation is abnormal. The protection system ensures that the power system equipment is kept healthy and functional (free from damage) whenever an abnormal situation occurs. The protection system also ensures the availability of optimal and reliability of power supply to consumers [2].

"Transformer differential protection." Devices that use time grading and directional detection to prevent earth faults and over currents are unable to precisely locate the fault and swiftly remove it from power networks. They therefore proposed differentiated protection as the better choice. It protects particular network segments or individual pieces of machinery, such as generators and transformers. It is usually applied when rapid fault clearance is necessary or achieving protection coordination between earth fault and current protection is difficult [3].

"Power Transformer Protection using Microcontroller Based Relay." CTs were replaced in their design to process the current signal with Hall effect current transducers, which have a wider frequency operating range and directly supply voltage comparable to the current signal. There is no longer a need for current to voltage conversion because the microcontroller only accepts voltage signals [4].

"Micro controller-based transformer protection." Uses four sensors to measure temperature, current, and voltage: an LM35 temperature sensor, an oil level sensor, a current sensor, and a voltage sensor. These three analog readings are linked to the analog pin of the Arduino programmable microcontroller. When these analog values are supplied into an analog to digital (A to D) converter, they are instantly converted to digital values. After reading each sensor value separately, the microcontroller will process the sensor data. Next, the values are sent directly through a Wi-Fi module, displaying the data for management in an internet-connected IOT (Internet of Things) region. Every value is compared to the threshold values, and the microcontroller will issue an alarm if a defect is found. When the relay detects a malfunction, it will cut off the transformer's power. A step-down transformer (230/12V) supplies electricity to the relay. The voltage regulator 7805 is used to regulate the 12V AC to DC and then back to +5V, which is necessary for the Arduino, LCD display, and other interfaced sensors to function [5].

"Design of a protective scheme for the distributed generation system in Rivers State." The Trans-Amadi 33kv network was built and simulated using the electrical transient analysis program (ETAP). In order of preference, the network simulation was conducted in three stages: building the ETAP network edit environment, putting the protection plan into action, and modeling network power flows [6].

"Simulation of differential relay for transformer protection." MATLAB/Simulink was used to operate and simulate a power system model. Between the 11/33kv power transformer and the transmission line in this model is a current relay protection mechanism. The electrical system to which the power transformer was attached included generator with three phases of power. It applies a load across this transformer, which is positioned between two circuit breakers, CB1 and CB2, in order to quantify the switching impact [7].

"Protection of transformer by using differential protection scheme." To protect transformers against a range of problems, different relaying techniques have been put out and put into practice. Overcurrent, overflow, and overheating-related relays shield the transformers from overloads and externally imposed conditions, while differential relays guard the transformers against internal defects. The configuration, testing, and display of a microcontroller-based relay system's functionality are all covered in this study, in addition to the layout and implementation of the system's both software and hardware [8].

"Power Transformer Protection using ANN and Wavelet Transforms." This study used the wavelet transform and Artificial Neural Network (ANN) approach to propose a three-phase power protection for transformers mechanism. The resultant current waves are disassembled using wavelet transformations; they use the ANN approach as a pattern classifier. Many case studies demonstrate how wavelet transformation efficiently permits preliminary feature extraction for a range of transitory settings. Very high accuracy and dependability can be achieved by combining ANN with wavelet processing. Furthermore, this combination improves speed and accuracy in identifying internal defects. An ANN and wavelet transform are used to construct simulation models for power transformer safety in the MATLAB/SIMULINK environment [9].

"Hermite transform-based algorithm to discriminate magnetizing currents in transformers." This work presents an innovative approach that uses the Hermite transform for recognizing brief occurrences in power transformers brought on by current transformer (CT) saturation and energization. Signals can be represented within the area of time-frequency and at different degrees of resolution using a signal processing technique called the Hermite transform. As per the theory of Hermite transform, the signals in the proposed scheme are examined with Gaussian derivatives. The recently presented technique is built upon a differential scheme that takes into account three functions: first, the positive half-cycle is analyzed, and the negative half-cycle is covered by the second one. In the event that the latter is a brand-new detection blocking function for transient situations, such as the order for the procedure being deactivated, the third role is going to ascertain whether the state is an internal problem. To verify the efficacy of the proposed technique, a number of fault scenarios are examined, including load switching, saturation of the current transformer, single-phase-to-ground faults, and internal and external failures. The results demonstrate the efficacy of the recommended approach, which enhances the capacity to differentiate between persistent issues and fleeting circumstances [10].

"Time domain differential protection scheme applied to power transformers." By combining intrinsic time-scale decomposition (ITD) with Ensemble of Bagged Trees (EBT) as a classifier; this study offers a fresh method of differential protection for power transformers. A monotonic trend signal in conjunction with proper rotation components (PRCs) comprise the ITD's breakdown of the input non-stationary signal. A time domain statistics feature generated from the ITD output is sent into the proposed scheme's EBT classifier. This classifier is used to classify a variety of events, including external faults, pitiful and recovery inrush currents, internal faults, and internal faults combined with inrush currents. Using the ITD and EBT tools together just demands a small data sample obtained after the fault to safeguard the transformer. Saturations of current transformers (CTs) effect on the system's functioning is assessed, and the accuracy of the suggested plan is confirmed by testing across a range of operational circumstances. Noise-intolerant and not reliant on transformer properties is the scheme. MATLAB and PSCAD/EMTDC were utilized to simulate the power systems [11].

"A Suggested Differential Protection Scheme for Power Transformer." A Real Power Differential Scheme (RPDS) is used in this study to safeguard power transformers. Utilizing the recommended RPDS for energy transformers, the power locations that are active during regular operation, switching, and power swing, internal, involving turn-to-turn as well as external defects are calculated. The suggested RPDS idea depends on the observation and comparison of the transformers main, secondary, and reactive powers. The recommended RPDS's dynamic reaction. is tested using a 300MVA, 220/66kv, Y/Δ transformer. Furthermore, after using MATLAB/Simulink to simulate the suggested method is assessed under several faults and switching scenarios. Furthermore, the RPDS's primary and secondary sides are examined for instances of inter-turn faults. Regarding the power differential system's high precision response, stability restrictions, good selectivity, speed, and sensitivity, the examination of the suggested scheme verifies its superiority in recognizing external and internal faults as well as magnetizing inrush currents. In summary, a wide variety of fault resistances are accurately detected for turn-to-turn failures by the suggested system, which fails at very low values [12].

"A fault analysis of 11kv distribution system (a case study of Ado Ekiti electrical power distribution district)." Ado Ekiti, the main political and economic hub of Ekiti State, was the study's location. It looked at the infrastructure for electric power and energy availability there. Throughout every relevant piece of a power distribution apparatus operating at 11kv was evaluated. The availability of power was taken into consideration by obtaining the necessary data on energy supplies, faults, and other outages. An examination of the distribution lines revealed that they were in rather poor condition, with nearly 40% of the spans not meeting criteria, 25% of the poles failing to meet a "goodness" criterion, and 33% of the cross-arms either broken or satisfactory. This article presents the findings of a study on the examination of the Ado Ekiti power distribution system's faults [13].

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.

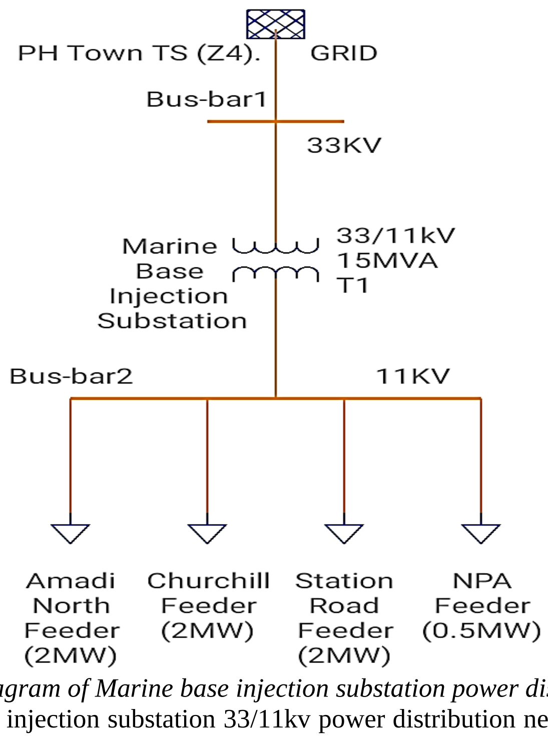

Figure 1: Line diagram of Marine base injection substation power distribution network

Figure 1 shows the Marine base injection substation 33/11kv power distribution network line diagram; the network is made up of Port Harcourt Town transmission station (PH Town TS) also known as Z4 located at Inzimiro supplying

33kv to bus-bar1. Transformer T1 connected to bus-ber1 stepping the voltage to 11kv; distributing this voltage to the four feeders through bus-bar2.

Table 1: Equipment of the Marine base injection substation power distribution network

S/N	Element	ID	Power Ratting
1	Transmission Station	PH Town TS (Z2)	
2	Transformer	T1	15MVA
3	Feeders	Amadi North	2MW
		Churchill	2MW
		Station Road	2MW
		NPA	0.5MW

Electrical Parameters of the Protection Scheme

Line, load and transformer data; and the existing information of the network received from PHED were used to determine the electrical parameters of the protection scheme.

Autocad 2D Design Software

Autocad 2D design software was used to design the diagrams displayed on this work.

Data source: Marine base 33/11kv injection substation, under the Port Harcourt Electricity Distribution Company (PHED) Moscow Road.

Method Used

The differential current method is being utilized in this study; it's a protection technique designed to identify flaws within a designated zone. By comparing the currents entering and exiting that zone, it operates. The current entering the zone and the current exiting it should be equal under normal circumstances. ($i_1 = i_2 \; or \; i_1 - i_2 = 0$). Any difference in current indicates a defect (fault) within the zone ($i_1 \neq i_2 \; or \; i_1 - i_2 = \Delta I$).

To reduce the currents entering and leaving the protected zoned $i_1 and \; i_2$, current transformers (CTs) are utilized. A differential relay is linked to the secondary windings of the CTs. The two currents are compared for phase and magnitude by the differential relay. Relays trip to isolate malfunctioning sections from the rest of the system when the difference between the two currents surpasses a certain threshold.

When talking about protection zone, it means the region between two current transformers (CTs); faults within this region is said to be internal faults and any fault located outside the two CTs are considered as external fault, hence the zone is protected and relay will not operate.

The transformer to be protected is a three-phase power transformer of 33/11kv, 15MVA; primary delta and secondary star connected.

Power Factor

The overall system power factor and reactive power losses in transformers and other distribution system equipment shall not be less than 0.85 lagging at the rated design throughout the station. The power factor shall be determined at the terminals of the transformer(s) [1].

Table 2: Data Used for Calculation and Simulation

S/N	Parameters	Size
1	One number of three-phase power transformer T1	15MVA/33/11kv
2	Three-Phase Source Input Grid.	33kv
3	Two number of three-phase circuit breakers.	High Voltage
4	Subsystem that handles the differential relay's duties.	5A
5	Four, Three-phase series RLC load: Amadi North, Churchill, Station Road and NPA Feeders.	6.5mw
6	Scopes.	2
7	Four RMS blocks, which are used to discretize signals.	50Hz
8	There are four bus bars.	33kv and 11kv
9	There are four load flow buses.	33kv and 11kv
10	Three number of stair generator (sample time).	0.0001s
11	Three number of three-phase fault (fault resistance).	0.001ohm
12	Base MVA	100
13	Incoming CTR33kv side	300/5
14	Outgoing CTR 11kv side	800/5
15	Four display blocks; output devices for the signal values to be shown.	

RESULTS AND DISCUSSIONS

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

Internal faults on all three phases are depicted in figure 2; the secondary side of the transformer is faulted at point 2, where the relay triggered a tripping signal that caused all three phases on the secondary side circuit breakers to open at a time of t=0.1s. Despite this, the transformer is not isolated from the grid. All the currents in the phases both primary and secondary shown in table 3 are faulty currents resulting to the tripping of the system.

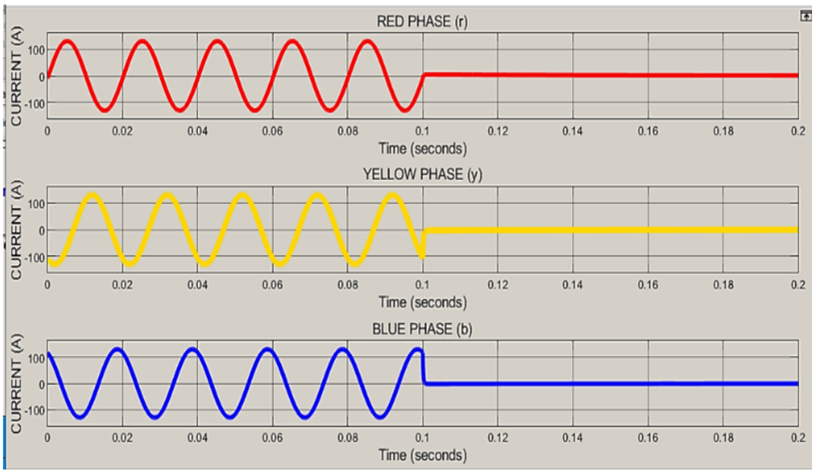

Figure 2: Simulation result at the secondary side when fault occurs at point 2 L-L-L-G

Table 3: Signal Statistics for Simulated results on L-L-L-G when fault occurs at point 2

Primary side					
Red Phase		**Yellow Phase**		**Blue Phase**	
Tripped Time (S)	Fault Current Value (A)	Tripped Time (S)	Fault Current Value (A)	Tripped Time (S)	Fault Current Value (A)
0.1	1225	0.1	1146	0.1	1184
Secondary side					
Red Phase		**Yellow Phase**		**Blue Phase**	
Tripped Time (S)	Fault Current Value (A)	Tripped Time (S)	Fault Current Value (A)	Tripped Time (S)	Fault Current Value (A)
0.1	65.59	0.1	67.31	0.1	64.33

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

Figure 3 shows external fault on all three phases from a fault at point3; being a fault outside the protected zone which occurs at a time of t=0.1s; since it is an external fault the secondary generated currents, just moving back and forth between the CTs in the lines and no current flows through the relays; thereby relays not operating. The relays will not initiate any tripping signals to the respective breakers; hence there was no tripping in the protection zone. All the currents in the phases both primary and secondary shown in table 4 are faulty currents.

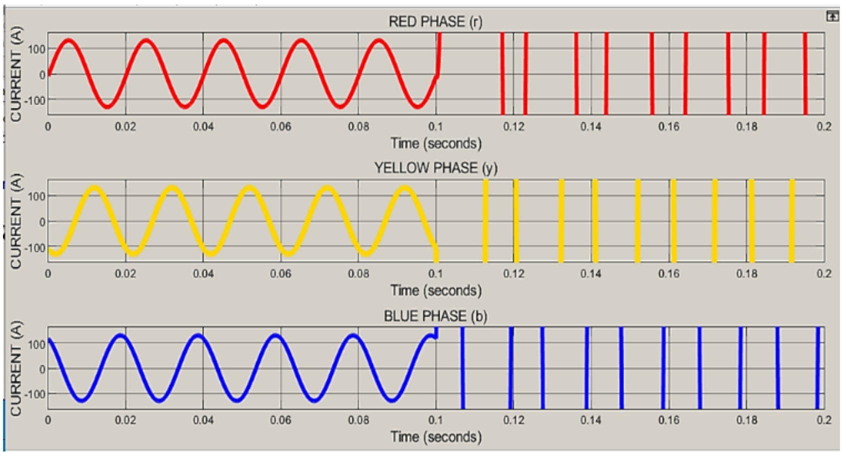

Figure 3: Simulation result at the secondary side when fault occurs at point 3 L-L-L-G

Table 4: Signal Statistics for Simulated results on L-L-L-G when fault occurs at point 3

Primary side

Red Phase		Yellow Phase		Blue Phase	
Tripped Time (S)	Fault Current Value (A)	Tripped Time (S)	Fault Current Value (A)	Tripped Time (S)	Fault Current Value (A)
Nil	1357	Nil	1228	Nil	1168
Secondary side					
Red Phase		**Yellow Phase**		**Blue Phase**	
Tripped Time (S)	Fault Current Value (A)	Tripped Time (S)	Fault Current Value (A)	Tripped Time (S)	Fault Current Value (A)
Nil	3771	Nil	3684	Nil	3504

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

The findings for a two line to ground fault (L-L-G) is displayed in figure 4; a fault that affected the red and yellow phases of the system was created at point 1; the relays in charge of both phases sensed the fault current and sent signals to the respective circuit breakers. As a result, the accompanying relay tripped the circuit breakers in a time of t=0.1 seconds; indicating that the fault at point 1 is an internal fault situated inside the protected zone. In this instance, it is evident that just the defective phases were separated from the power source. Table 5 shows the fault current on the red and yellow phases as the faulty phases.

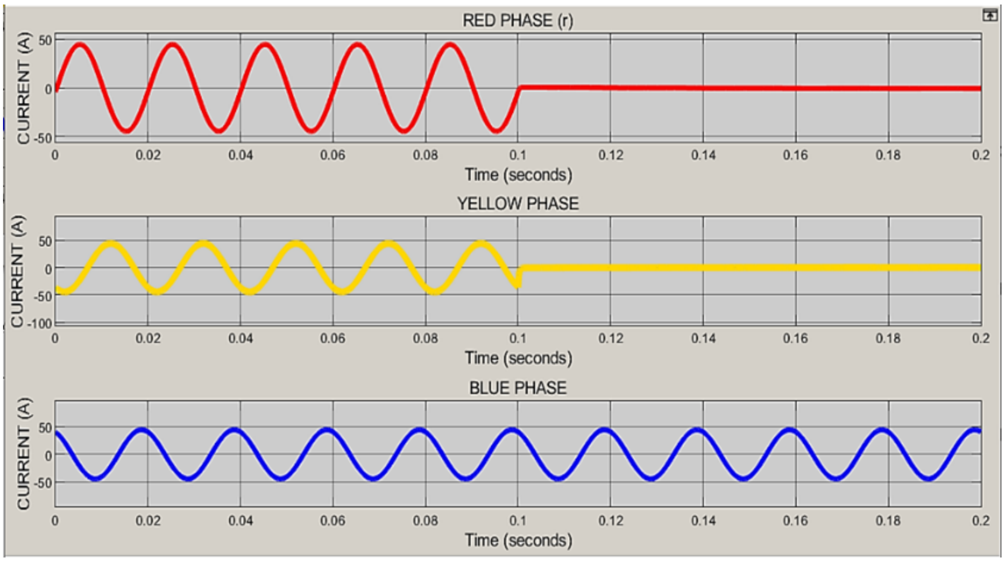

Figure 4: Simulation result at the primary side when fault occurs at point 1 (L-L-G)

Table 5: Signal Statistics for Simulated results on L-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)	Fault Current Value (A)	Tripped Time (S)	Fault Current Value (A)
0.1	25.55	0.1	25.78	Nil	30.56
Secondary side					
Red Phase		**Yellow Phase**		**Blue Phase**	
Tripped Time (S)	Fault Current Value (A)	Tripped Time (S)	Fault Current Value (A)	Tripped Time (S)	Fault Current Value (A)
0.1	74.70	0.1	75.40	Nil	89.46

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

The outcomes of the two lines to ground fault (L-L-G) are also displayed in table 6 and figure 5; the yellow and blue phases were impacted by a fault that occurred in the system at point 2. The relays in charge of each phase detected the fault current and transmitted signals to the corresponding circuit breakers, which tripped at t=0.1s. The data indicates that the source of failure is an internal fault situated within the protected zone. Consequently, the relays connected to phases tripped the circuit breakers.

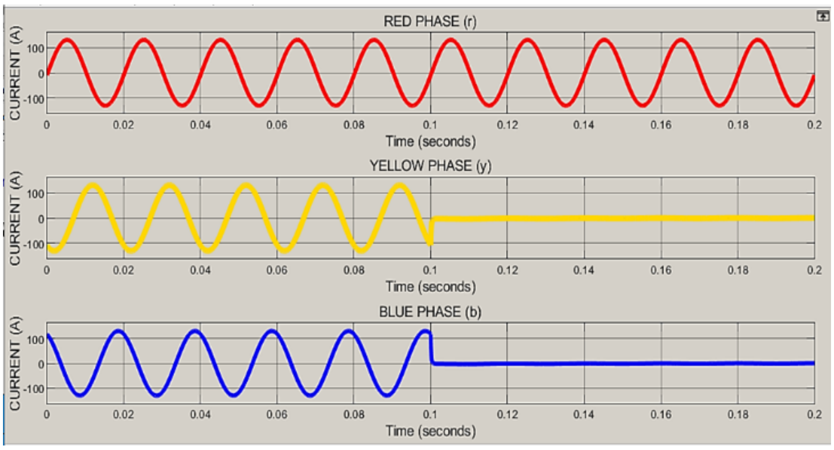

Figure 5: Simulation result on the secondary side when fault occurs at point 2 (L-L-G)

Table 6: Signal Statistics for Simulated results on L-L-G fault when fault occurs at point 2

Primary side					
Red Phase		**Yellow Phase**		**Blue Phase**	
Tripped Time (S)	Fault Current Value (A)	Tripped Time (S)	Fault Current Value (A)	Tripped Time (S)	Fault Current Value (A)
Nil	31.98	0.1	1132	0.1	1204
Secondary side					
Red Phase		**Yellow Phase**		**Blue Phase**	
Tripped Time (S)	Fault Current Value (A)	Tripped Time (S)	Fault Current Value (A)	Tripped Time (S)	Fault Current Value (A)
Nil	93.71	0.1	68.08	0.1	64.91

CONCLUSION

This work showcases protection for the 15MVA, 33/11kv Marine base injection substation power distribution network. By proposing the use of an adaptive restraint current technique in the relay (for the relay to operate as required, the current in the operating coil of the current transformers I_{OP} must not be less than 10% of the restraint coil average current I_r, i.e., $I_{OP} \geq [\frac{10}{100} * 4.647)$. This, technique is designed to improve the relay accuracy and reliability under varying load conditions. This technique dynamically, adjusts the relay's restraint level based on the measured primary current, ensuring that the relay operates within its safe operating range while maintaining high accuracy. The inclusion of adaptive restraint technique has improved the scheme's sensitivity to internal faults while maintaining selectivity against external faults. The incorporation of zero-sequence current into the restraint calculation has enhanced the scheme's ability to discriminate between internal and external faults, especially in grounded systems.

The study also proposed the use of a matching CT with a ratio of 1:0.8886 to be connected in parallel with CT_2 at the secondary side of the power transformer; so current that flows out of the matching CT towards the differential relay will be equal to the current that will flow out of CT_1 towards the differential relay. The resultant current that will flow through the differential relay will be zero; hence, $\triangle_I = i_1 = i_2$ or $\triangle_I = i_1 - i_2 = 0$; there will be no tripping but with a fault condition $\triangle_I = i_1 \neq i_2$ or $\triangle_I = i_1 - 1_2 = i_f$ i.e., $\triangle_I = i_f$; if this fault current that will flow into the differential relay exceeds the pre-set value of 10% of the restraint coil average current ($0.4647A$), and last longer than the delay-time on the relay; then the relay senses danger and issue out a tripping signal to the circuit breaker for isolation.

REFERENCES

[1]. RC Ijeoma, and HN Amadi, Analysis of a Grid-Based Rural Electrification Scheme for Ekpe-Aggah Community in Rivers State, Nigeria. International journal of Engineering and Modern Technology (IJEMT), vol. 10, no. 6, pp 148-158, 2024.

[2]. J P Kelly, Modeling and Simulation of Power System Protection Relays in a Transmission-Level Application. Theses and Dissertations, 355, 1-163, 2021.

[3]. AJ Onah, and EE Ezema, Transformer Differential Protection. European Journal of Engineering Research and Science (EJERS), 5(8), 891-898, 2020.

[4]. SM Bashi, N Marium, and N Rafa, Power Transformer Protection using Micro controller Based Relay. Journal of Applied Science, 7(12), 1602-1607, 2007.

[5]. HC Kiran, MS Madhushree, NP Roopesh, S Shivasharana and CB Shankaralingappa, Micro Controller Based Transformer Protection. International Journal of Research Publication and Reviews, 2(8), 670-676, 2021.

[6]. US Okogbule,CO Ahiakwo, and IC Okara, Design of a Protective Scheme for The Distributed Generation System in Rivers State. IRE Journals, 5(6), 88-100, 2021.

[7]. NS Azizan, CL Wooi, B Ismail, SNM Arshad, M Isa, WA Mustafa, and MNK Rohani, Simulation of Differential Relay for Transformer Protection. 1st International Symposium on Engineering and Technology (ISETech) 2019, 1-13, 2019.

[8]. R Dekate, and N Kamdi, Protection of Transformer by Using Differential protection Scheme. Electrical Engineering Suryodaya College of Engineering & Technology, Nagpur, 4(2), 4732-4734, 2018.

[9]. R Naveena-Bhargavi, ML Swarupa, and M Rajitha, Power Transformer Protection using ANN and Wavelet Transforms. 7th International Conference on Advanced Computing & Communication Systems (ICACCS), 161-166, 2021.

[10]. D Guillen, L Olveres, H Esponda, B Escalante-Ramirez, V Torres-García, and R Tapia-Olvera, Hermite transform-based algorithm to discriminate magnetizing currents in transformers. Sustainable Energy, Grids and Networks, Vol. 27, 1-6, 2021.

[11]. Z Moravej, A Ebrahimi, M Pazoki, and M Barati, Time domain differential protection scheme applied to power transformers. International Journal of Electrical Power & Energy Systems, Vol. 154, 1-27, 2023.

[12]. ES Ahmed, and RA El-Sehiemy, A Suggested Differential Protection Scheme for Power Transformer. College of Engineering, Kafrelsheikh University, Kafrelsheikh, Egypt, Int. Rev. Appl. Sci. Eng., 5(2), 91-103, 2014.

[13]. K Olusuyi, AS Oluwole, T Adefarati, and AK Babarinde, A Fault Analysis of 11kv Distribution System (A Case Study of Ado Ekiti Electrical Power Distribution District). American Journal of Electrical Power and Energy Systems, 3(2), 27-36, 2014.