IMPACT OF FAULT RESISTANCE ON DISTANCE RELAYING OF AHOADA-YENAGOA TRANSMISSION LINE USING NEPLAN

ABSTRACT

Relay protection schemes play a vital part in guaranteeing reliability and integrity of electrical power networks by promptly detecting and isolating faults in the transmission network. Fault resistance encountered during a fault event, is a crucial parameter that significantly influences the effectiveness of relay protection systems. This paper investigates the performance of a distance relying system under different fault resistance using NEPLAN software environment on a 46-km Ahoada to Yenagoa transmission line. The performance of the distance protection relaying system under single line to ground (SLG) at 80% of the transmission line with fault resistances of 0.65Ω and 2.9Ω was modeled and analyzed using NEPLAN. From our investigation, the result reveal that when a fault resistance of 0.65 Ω and 2.9 Ω was introduced in the system during a SLG at 80% of the line (zone 1), the apparent impedance seen by the relay increased from 5.475 Ω without fault resistance to 5.602Ω and 6.407 Ω respectively. The results show that for a fault resistance of 0.65 Ω, the apparent impedances (ZAPP) trajectory falls inside the impedance characteristic of zone 2 instead of zone 1 while a fault resistance of 2.9 Ω fall outside zone 2. The findings highlight the significance of fault resistance in transmission line relaying for distance protection.

Keywords: Distance Relaying; NEPLAN, Fault resistance; Transmission line; Distance protection.

1. INTRODUCTION

The effective and dependable transfer of electrical energy from power producing sources to end users is dependent on power transmission lines. These extensive networks of conductors facilitate the long-distance transport of electricity, connecting power plants to distribution centers, industrial facilities, and residential areas. Understanding the key aspects of power transmission lines is essential for grasping the complexities and challenges associated with the reliable operation of electrical grids. Transmission lines are the connecting links between all generating stations, distribution network, and the entire individual load through power transformers, therefore, proper protection system should be incorporated into the transmission system to protect the power system equipment against system failure and improve reliability Because transmission lines are basically responsible for 85-87% of power system faults, and it is given serious attention in power system engineering [1]. Since no power system can be built to never fail, an autonomous protective device is required to isolate the problematic component as soon as possible and maintain normal operation of the system's healthy portion. The protective relay system's dependability is largely responsible for the operational reliability of the electrical system and mass power transfer. [2]. Distance relays, which rely on measuring the impedance to a fault location, are particularly sensitive to variations in fault resistance. It It accomplishes selection based on impedance, and since the impedance relates to the distance between the relay and the fault point, the relay immediately reveals the fault location [3]. Relay protection systems vital part in guaranteeing the stability and integrity of electrical power systems by promptly detecting and isolating faults. However, the relay operation is affected by factors such as fault resistance, multiple feeder sections, load current, coupling of parallel lines, etc. [4]. Fault resistance plays a critical role in influencing fault currents, and higher levels of fault resistance can lead to lower fault current magnitudes, posing challenges for conventional protection relays in accurately detecting faults. While traditional relays perform well in the presence of low-resistance faults, they may struggle to measure fault impedance accurately in the case of high-resistance faults. Depending on the direction of current flow and the strength of fault resistance, relays may overreach or underreach. Fault resistance is especially crucial in distance relaying, and its neglect can lead to internal flow, causing malfunctions in the distance relay. Overreaching occurrences, unbalanced loads, and line asymmetry can impact the effectiveness of distance protection.The reliability of power supply in Nigeria, including the 45-kilometer Ahoada to Yenagoa transmission lines connecting Rivers State and Bayelsa, has been hampered by poor transmission infrastructure and malfunctions in protective relays due to aging and insufficient generation. The impact of fault resistance, leading to voltage transformer errors, is identified as a significant concern in short transmission line protection. Reports from the Transmission Company of Nigeria (TCN) in Port-Harcourt, Rivers State, highlight numerous mal-operations in the transmission line protective relay system. This paper aims to investigate the specific impact of fault resistance on the distance relaying system of the Ahoada to Yenagoa 132kV transmission line, shedding light on the challenges posed by fault resistance and its implications for the reliability and proper functioning of the protective relay system.

2.DISTANCE RELAY PROTECTION

The protection zones are not equal in distance protection, which is a non-unit form of protection. It is frequently utilized to protect transmission lines and can be used as both primary and backup protection. [5]. Ohm's law forms the foundation of distance protection. [6].The impedance detected at the relay position by the relay is less under abnormal or fault condition than it is under the conditions of healthy power transfer. It is in this difference that distance protection is based on. When the distance relays receive signals derived from voltage and current and, measured the line impedance, it initiates circuit breaker tripping when the measured impedance is less than a predetermined value or setting. The protection relay operates only in fault condition and is designed to discriminate against all load conditions (up to the thermal limits) and against external fault [7]. The features of distance relays are to prevent miss-functioning in the absence of a fault and to guarantee proper operation in the event of a short circuit fault within the protected zone [8]. Plotting the two input variables relative to one other yields operational characteristics for the common types of distance relays either circles or straight lines on an R/X diagram. Numerous properties, like the ohm characteristic, reactance characteristic, quadrilateral characteristic, etc., are present in the distance relay. The primary reason for using the quadrilateral relay characteristic is that it makes it possible to independently adjust the ground fault resistive reach based on the forward reach and source impedance, hence achieving the necessary ground fault resistive coverage. For short lines, it therefore offers superior resistive coverage compared toall mho type characteristics. [9]. The relay characteristic, depicted in Figure 1, illustrates the quadrilateral design used for distance relays, featuring three operational zones. The operating times associated with these zones are 30 milliseconds, 200 milliseconds, and 3 seconds for the first, second, and third zones, respectively. Zone 1 is designed to trip instantly upon detecting a fault, covering approximately 80–90% of the primary protected line. A safety margin of 10 to 20% is incorporated to mitigate inaccuracies in voltage and current transformer measurements and prevent overreaching of Zone 1 protection. Zone 2 extends the coverage to 10-20% beyond the main line and is synchronized with a time delay to allow Zone 1 to respond first. Additionally, Zone 2 covers the entire protected line and 50% of the shorted neighboring line. Zone 3, with the broadest reach, serves as remote backup protection for nearby lines. This relay configuration enhances the reliability and efficiency of the distance protection system [10].

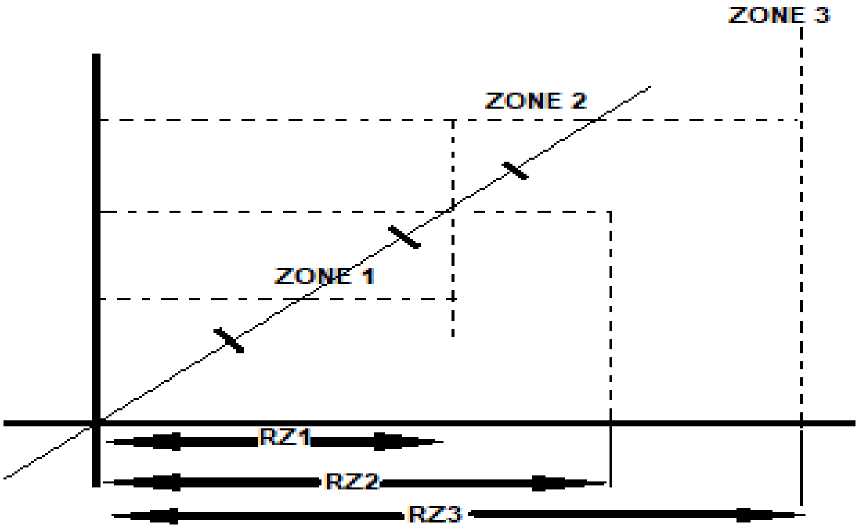

Fig 1 Quadrilateral relay characteristic

3. AHOADA YENAGOA TRANSMISSION LINE TRIPPING REPORT

Yenagoa, the capital of Bayelsa state in Nigeria, is experiencing rapid growth, emerging as one of the country's fastest-growing cities with a population exceeding 300,000 people. The city's development is marked by an increasing demand for electricity, primarily driven by the influx of small and medium-scale industries, as well as government and private infrastructure projects. Despite this surge in electricity demand, the city faces challenges in power supply, with interruptions attributed to issues such as the transmission network failure between Ahoada and Yenagoa or insufficient power from the Transmission Company of Nigeria. The single-line diagram of the 46 km Ahoada - Yenagoa transmission network is depicted in Figure 2.

The history of the tripping report of the 46 km Ahoada to Yenagoa Transmission line indicates a malfunction in the distance relay operation, and be may potentially linked to higher fault resistance. Table 1 presents the relay trip report, revealing instances of mal-operation. In the first fault report (serial number one), a single line to ground (SLG) fault is noted at 37.66 km, which falls outside the expected zone 1 coverage of 80% of the line at 36.8 km. This discrepancy suggests a misalignment between the reported fault location and the designated zone, indicating a malfunction in the distance relay. Moreover, a fault reported at 38.57 km is indicated in zone 1, surpassing the 36.8-km threshold, further confirming the inaccuracies in relay operation. These findings highlight the importance of addressing distance relay malfunctions and the potential influence of higher fault resistance on the reliability of the protection system. The influence of fault resistance can lead to the occurrence of internal flows within the system. These internal flows, if not appropriately addressed, can trigger malfunctions in the distance protection relaying system, resulting in under-reaching occurrences [11][12].

Understanding the historical fault data and analyzing the performance of relays in response to these events is crucial for evaluating the reliability and effectiveness of the protective measures in power systems. Historical fault data provides valuable insights into the types, frequencies, and characteristics of faults that have occurred over time, allowing for the identification of patterns, weaknesses, and areas for improvement in relay protection systems.

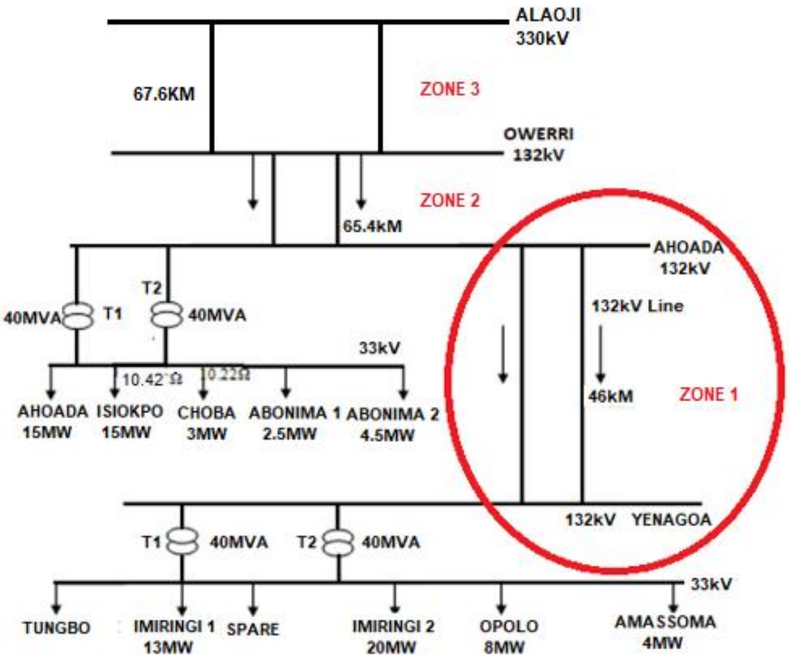

Fig 2 Single Line diagram of 132kV line from Owerri to Ahoada to Yenagoa

Table 1: Tripping Report of Ahoada -Yenagoa Transmission line

S /n	Date	Fault Location (km)	Target Zone	Circuit Breaker	Phase A Voltage (KV)	Phase B Voltage (KV)	Phase C Voltage (KV)	Phase A Current (kA)	Phase B Current (kA)	Phase C Current
1	6/4/2016	37.66	Zone 1 C-GND	BK1&2-Open	63∠18.6◌̊	65∠-142.4^0	28∠105.6◌̊	200∠-139.3	260∠-138.9	1250∠41.2
2	4/9/2016	38.57	Zone 1 A-GND	BK1&2-Open	27∠9.5	85∠-122.5	29∠67.9	1300∠-67	190∠129.6	374∠42

3	2/1/2017	25.67	Zone 2 A-GND	BK 1& 2-Open	33∠-34	89∠-108.8	66∠109	1100∠-82.7	160∠67.9	258∠-66.6
4	4/4/2017	30.25	Zone 2 C-GND	BK1&2-Open	30∠0.7	30∠-119.3	33∠120.8	1∠48.8	1∠-63.2	1200∠42.4
5	9/11/2016	40.51	Zone 2 A&B-Phases	BK 1& 2-Open	45∠-50.6	45∠-67.9	65∠120.7	504∠-53.9	506∠126.2	265∠-110.1
6	4/3/2017	57.24	Zone 3 C-GND	BK 1& 2-Open	66∠23.9	60∠-139.2	18∠118	180∠-127.5	185∠94.2	1136∠38.8
7	10/5/2016	17.56	Zone 1 A&C-GND	BK 1& 2-Open	27∠11.3	86∠-122.3	29∠69.1	1300∠-83.2	135∠126.2	1260∠32.3

4. MATERIAL AND METHOD

4.1 NEPLAN Simulation Tool

One of the most comprehensive planning, optimization, and simulation tools for generation, transmission, distribution, and industrial networks is the NEPLAN power system analysis Tool [13]. It may be utilized with several documents and windows and features the easiest-to-use graphical user interface. All equipment can be input graphically and in tables in the NEPLAN work environment. To handle network data more quickly and easily, NEPLAN maintains all of it in an internal database, including single line diagrams, protection devices, controllers, calculation parameters, and results. In this research, the NEPLAN tool will be used to model a 46 km Ahoada to Yenagoa transmission network and investigate the impact of fault resistance on the distance relay operation.

4.2 Method

The paper analyzes the impact of fault resistance on the performance of the distance protection relay on a 46 km Ahoada Yenagoa transmission network. The transmission system parameters are shown in Table 2. The procedures of the research consist of several steps;

1. Study of the effect of fault resistance on distance protection relaying
2. Model and simulate the 46 km Ahoada to Yenagoa transmission network with SLG fault and fault resistance values of 0.65Ω and 2.9Ω.
3. Analyse the effect of the fault resistance values on the performance of the distance protection system.

4.2.1. Effect of Fault resistance on distance protectionrelaying

The length of the protected line is proportional to the fault impedance and it is measured by distance protection relays. However, in practice, there is occasionally a finite amount of resistance present in the phase and ground faults. When a fault occurs from one line to the ground, the ground's resistance and the tower footing resistance combines to make fault resistance [14], when a fault occurs from one line to another, the arc resistance creates fault resistance. According to [15],[16], fault resistance during phase or ground faults causes an error in the fault distance estimation and may cause a traditional distance relay to operate unreliably.
The cases that are the most serious are;

i. A close-in fault is one that occurs near to the relaying point, either forward or backward.
ii. A remote end fault is one that occurs close to the end of the protected zone.

For SLG fault with high fault resistance can make the resistance to measure incorrect value thereby making the relay to under reach or over reach which depend on the forward/ backward flow direction. [17]. Fault resistance is a major problem in distance relaying of short transmission line because it increase voltage transformer error [18].

Using figure 3,the effect of fault resistance on the apparent impedance (z_{app}) observed by the distance relay is examined with SLG fault. Using figure 2, equation 1 provides the voltage at the problem location.

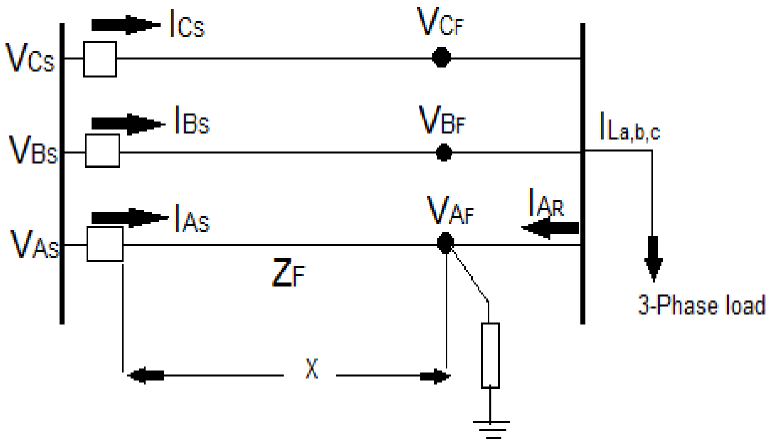

Fig 3 Short circuit transmission line [16]

$$V_{AF} = V_{AS} - [Z_A][I_S] \qquad (1)$$

where x is the distance between the relay location and the fault location, [ZA] is the impedance vector, $[I_S]$ is the current vector, and V_{AS} is the phase A voltage at the relay location. Equation 1 shows the voltage at the fault location which can be re-written as;

$$V_{AF} = V_{AS} - x(Z_{AA}I_{AS} + Z_{AB}I_{BS} + Z_{AC}I_{CS}) \qquad (2)$$

Another way to express the voltage at the fault location is as follows:

$$V_{AF} = R_F \,.\, I_{AF} \qquad (3)$$

Where R_F is the fault resistance at the fault location, I_{AF} is the fault current.

$$V_{AF} = I_{AS} + I_{AR} \qquad (4)$$

When equation 4 and equation 3 are substituted in equation 2, we have equation 5;

$$V_{AF} = R_F(I_{AR} + I_{AS}) - x(Z_{AA}I_{AS} + Z_{AB}I_{BS} + Z_{AC}I_{CS}) \qquad (5)$$

The apparent resistance that the relay observes at the relay point is represented by equation 6.

$$Z_{APP} = \frac{V_{AS}}{I_{AS}} \qquad (6)$$

As a result, the apparent impedance observed by the relay with the influence of the fault resistance may be found using equations 2, 5, and 6.

$$Z_{APP} = x.\left[Z_{AA} + Z_{AB}\frac{I_{BS}}{I_{AS}} + Z_{AC}\frac{I_{CS}}{I_{AS}}\right] + R_F\left[1 + \frac{I_{AR}}{I_{AS}}\right] \qquad (7)$$

Equation 7 illustrates how the impedance between the fault location and the relay location, as well as the fault resistance's contribution, constitute the apparent impedance perceived by the relay. Because the apparent impedance is outside zone 1, as indicated in figure 4, the fault resistance has the effect of preventing the relay from operating [14].

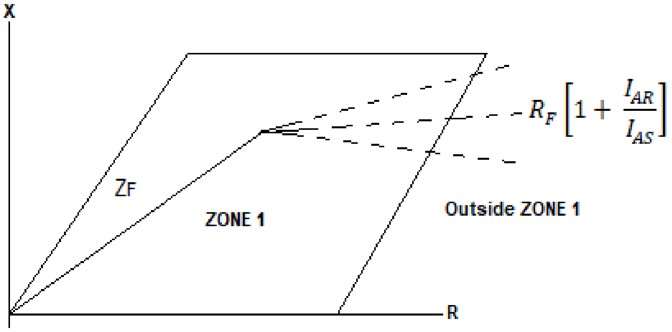

Fig 4 Fault resistance causing the Distance Relay to operate improperly

4.2.2. Modeling of the Ahoada-Yenagoa transmission line

The quadrilateral relay in NEPLAN relay library is used to model and investigate the Ahoada to Yenagoa transmission network. The 132 kV Ahoada to Yenagoa transmission line and protective relay parameters are shown in Table 2. The 46 km transmission network is a double circuit line and consists of current transformer, voltage transformer, distance relays and circuit breakers. The modeled transmission network and relay algorithm (flow chart) in NAPLAN are shown in Figure 5 and figure 6 respectively. A SLG fault is simulated with different fault resistance values is modelled to understand the impact on the distance protection relay protection,

Table 2: Ahoada -Yenagoa Transmission line Parameters

Parameter Description (Ahoada–Yenagoa)	**Value**	**Units**
line Voltage	132	KV
Nominal relay current (I_r)	1	A
Frequency	50	Hz
Line length	46	Km
Voltage transformer ratio (VTR)	132000:110	V
Current transformer ratio (CVR)	400:01:00	A
Positive sequence impedance (Z_{L1} (mag)	4.79	Ω
Positive sequence impedance (phase angle) (Z_{L1}ang))	84.8	Deg
Zero sequence line resistance (Z_{L0} (mag))	0.1239	Ω
Zero sequence line reactance (Z_{L0})	0.4089	Ω
ACSR (Conductor size)	2×150	mm^2

Source: Protection Department of Transmission Company of Nigerian, Port Harcourt, Rivers State, Nigeria

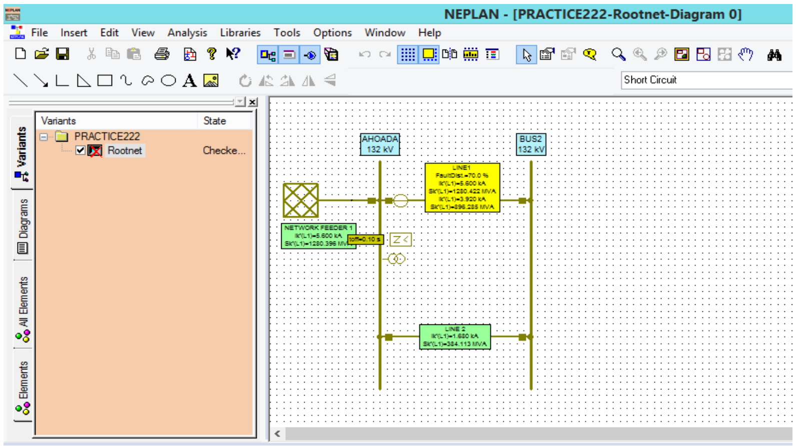

Fig 5 Modelled Ahoada –Yenagoa Transmission Network

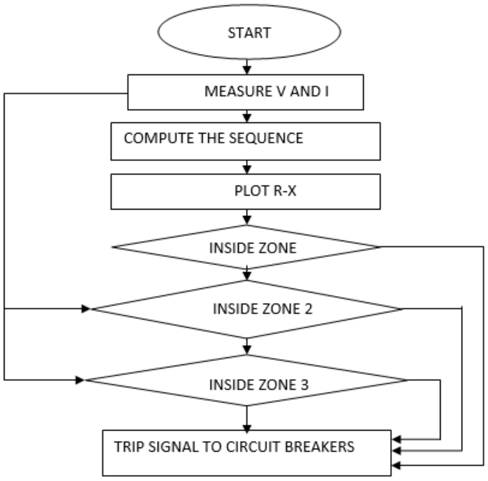

Fig 6: Relay Algorithm (Flow Chart)

5. RESULTS AND DISCUSSION

5.1 SLG Fault without Fault Resistance (R_f).

In this particular scenario, the protection zone has been meticulously set to encompass 80% of the transmission line originating from Ahoada.. When an SLG fault was introduce at 80% of the transmission line, The apparent impedance observed by the relay under these conditions was measured at 5.475 Ω.This observed impedance value is a critical parameter, as it signifies the electrical characteristics of the fault and becomes a key input for the distance relay's decision-making process. Upon analysis, it is noteworthy that the trajectory of the apparent impedances (Z_R) falls within the characteristic zone 1 of the R-X plane, as illustrated in Figure 7. The characteristic zone provides a graphical representation of acceptable impedance values for correct relay operation. The fact that the trajectory aligns within the designated zone 1 underscores the accuracy and reliability of the distance relays in responding to the SLG fault scenario.

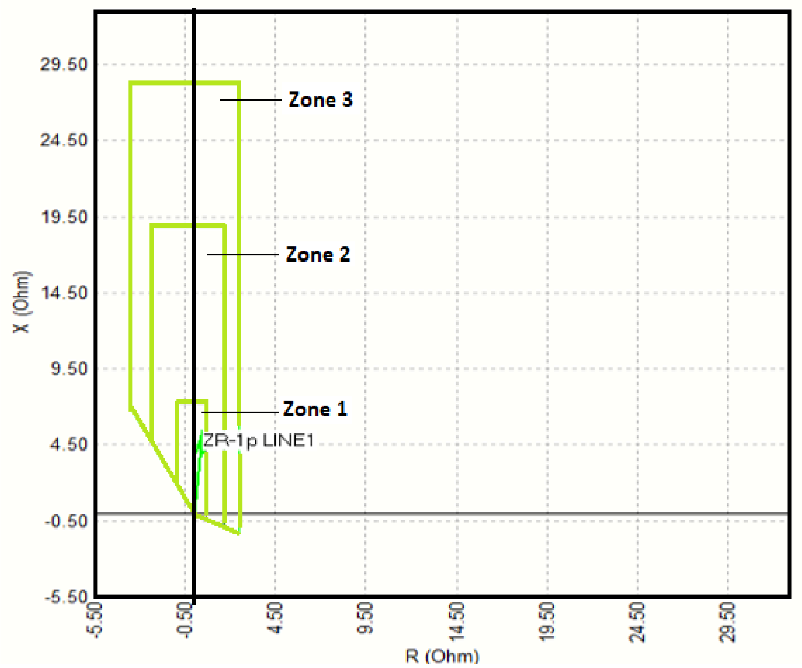

Fig 7: SLG fault at 80% from Ahoada Bus 1 (zone 1)

5.2 SLG fault with fault resistance (RF) of 0.65 Ω

In the given scenario, the apparent impedance encountered by the distance relay is influenced by a SLG fault occurring at 80% of the transmission line. This impedance is measured at 5.602 when a fault resistance of 0.65 is introduced. It's noteworthy that the inclusion of the fault resistance has led to a discernible impact on the relay's observations. Prior to the fault, the nominal impedance registered by the distance relay was 5.475 Ω. However, the introduction of the fault resistance has caused the observed impedance to deviate from this baseline, resulting in a higher value of 5.602 Ω. This shift is crucial in understanding the relay's behavior and its responsiveness to system anomalies. Figure 8 provides a visual representation of the impedance trajectory, shedding light on the relay's response to the fault. Notably, the trajectory depicted in the figure indicates that the current impedance observed by the relay falls outside of the designated zone 1 but remains within zone 2. This deviation from the expected impedance range suggests that the relay is now operating in a zone that is not intended for the detection of faults

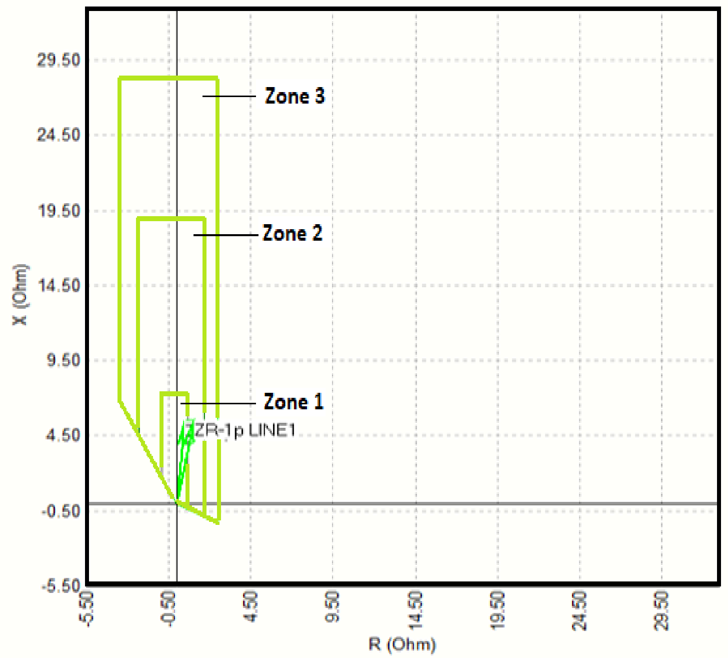

Fig 8: Impedance characteristics of SLG fault with fault resistance of 0.65Ω at 80% from Ahoada.

5.3 SLG fault with fault resistance (RF) of 2.9 Ω

To gain a comprehensive understanding of the apparent impedance behavior observed by the distance relay under specific conditions, a deliberate manipulation of the fault parameters was undertaken. In this context, the fault resistance, which plays a crucial role in shaping the relay's response, was intentionally increased to a significantly larger value of 2.9 Ω. This deliberate adjustment aims to explore the relay's behavior under more extreme fault conditions. When an SLG fault at 80% of the transmission line is coupled with this heightened fault resistance of 2.9 Ω, the distance relay registers an apparent impedance of 6.407 Ω. This increase in impedance, compared to the previous scenarios, is a direct consequence of the elevated fault resistance, demonstrating the sensitivity of the relay's measurements to changes in system parameters. Figure 9 serves as a visual representation of the relay's observed impedance trajectory under these conditions. The graphical depiction illustrates a clear deviation from the characteristic zones, namely zone 1 and zone 2. This deviation is indicative of the relay operating in a region that was not originally intended for fault detection. The figure encapsulates the intricate dynamics between fault parameters and relay response, providing valuable insights into the relay's behaviour. It is crucial to note that Figure 9, presented in the context of measuring fault impedance, showcases how the distance relay, under the influence of the heightened fault resistance, inaccurately gauges the fault impedance. This miscalculation, in turn, leads to the relay falling into zone 1 under-reach, indicating a failure to correctly identify and respond to the fault. The relay's under-reach in zone 1 signifies a potential vulnerability in its protective capabilities, underscoring the importance of precise fault parameter estimation for reliable relay operation.

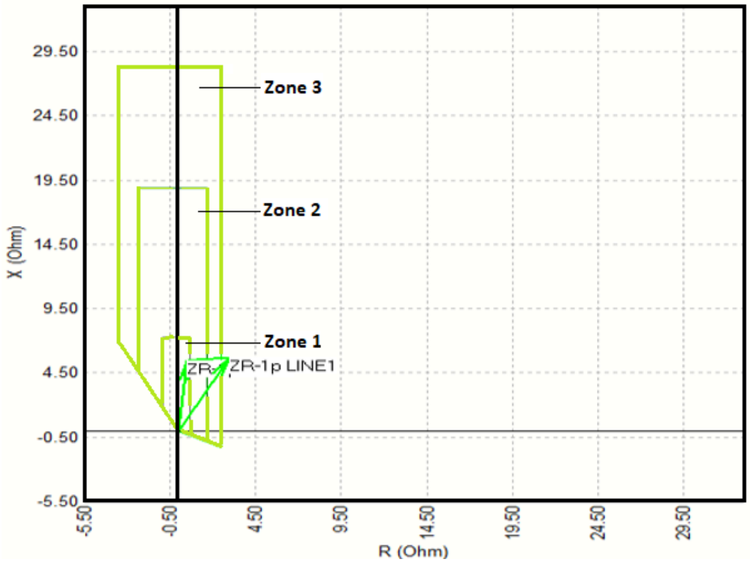

Fig 9: SLG fault at 80% with fault resistance of 2.9Ω from Ahoada

6. CONCLUSION

This paper employs the NEPLAN simulation software to conduct a modeling and analysis of the performance of a distance protection scheme applied to a 46km Ahoada to Yenagoa transmission network. The primary focus of the investigation is on understanding how the distance protection scheme behaves under SLG fault scenarios, specifically when different fault resistance values of 0.65Ω and 2.9Ω are introduced. The utilization of NEPLAN simulation software provides a powerful platform for creating a virtual representation of the transmission network and its associated protection system. Through simulation, the we can observe and evaluate the response of the distance protection scheme to different fault conditions, offering valuable insights into the system's behavior under dynamic scenarios. The findings of the study underscore the significant impact of fault resistance on the operation of the distance protection relaying system in the transmission network. The inclusion of fault resistance values, ranging from 0.65Ω to 2.9Ω, allows for a comprehensive exploration of the relay's behavior in response to varying degrees of fault severity. One of the key observations highlighted in the study is the crucial role that fault resistance plays in the proper functioning of distance protection relaying. The results reveal that ignoring the influence of fault resistance can lead to the occurrence of internal flows within the system. These internal flows, if not appropriately addressed, can trigger malfunctions in the distance protection relaying system, resulting in under-reaching occurrences. The specific case study of the 46km Ahoada to Yenagoa transmission line serves as a practical illustration of the implications of neglecting fault resistance. The investigation sheds light on instances where the distance protection relaying system exhibits under-reaching behavior, a phenomenon that compromises the system's ability to accurately detect and respond to faults

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AUTHORS’ CONTRIBUTIONS

Author A (Priye Kenneth Aina) developed the study process , model and simulate the system under investigation, and analyze the results.
Author B (Sunday Ugemuge) wrote some of the literature review and contributed in analyzing the article.

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