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# Performance Evaluation of the Distance Relays at the Delta Region for 132 kV Transmission network

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**ABSTRACT**
This study was carried out to determine the performance evaluation of the distance relays at the Delta region of the 132kV Transmission network. The research assesses the performance of the Delta relays $R_1$ and $R_2$ at Oghara-Amukpe line, which is the point of fault. The methodology used in this research was to carry out a power flow and short circuit studies to determine the relay impedance, $Z_R$ at the R-X plane of the Oghara-Amukpe line. The network was simulated in Neplan software. The short circuit and power flow studies of the distance relays were carried out using the data obtained from Transmission Company of Nigeria (TCN) for this network as input. The input data are: Voltage Transformer rating of 132 kV, Power Transformer rating of 90MVA, Current Transformer with a rating of 400A, Current Transformer ratio of 400/1A, Resistance/kilometer of 0.222ohm/km and Reactance/kilometer of 0.4281ohm/km. The network under study starting from TCN Benin covered Benin-Oghara, Oghara-Amukpe, Amukpe-Delta, Delta-Effurun, Delta-Ughelli and terminates at Ughelli transmission bus. The results obtained showed that relay 1 ($R_1$) and relay 2 ($R_2$) at zone two (2) had an un-instantaneous tripping action at a delayed tripping time of 0.5s for relay 1 and 0.1s for relay 2, which was an instantaneous tripping action at 81-99% fault distances at zone two (2) end and zone 3 entrance. Also, relay 1 ($R_1$) at zone one (1) during the three-phase fault had a fast tripping time of 0.5s at the entrance to the line and had un-instantaneous tripping action at 0.13s at 60-80% fault distances at zone one (1) end. The line had an instantaneous tripping action during the three-phase fault due to the slow tripping of relay 1 ($R_1$) and the fast tripping of relay 2 ($R_2$) at zones 1 and 2 respectively, which caused the distance relays to malfunction as a result of the high fault current of 2.891 kA at the faulted line causing low impedance of 12.91 ohms at fault condition, which is experienced by the distance relays at the Oghara-Amukpe transmission line.

**Keywords**: Performance, Evaluation, Distance Relay, Delta Region, Transmission, faulted line etc.

## I. INTRODUCTION

The distance protection scheme is normally applied to protect transmission lines. It acts as the main protection for overhead transmission lines. It also functions as a backup protection to the linking parts of the network such as bus bars, transformers, circuit breakers, switch gears, protection relays and feeder lines [7]. Distance protection is faster and more selective than over-current protection. It is also less prone to fluctuations in the power system conditions. An additional benefit of the distance protection is that it can be adapted easily to a unit protection scheme when applied with a communication connection [12]. Basically, a distance relay controls the impedance of the faulted portion of a transmission line from the measured voltages and currents at the relay location. Distance relay is generally used for medium and long transmission lines [1]. The distance relay calculates the impedance using voltage and current parameters to determine if the fault is within the protection zone or outside the protection zone of the transmission line network. When the measured fault impedance is matched with the impedance of the transmission line to be protected, one can determine if a fault exists on the transmission line between the relay and the fault point or not [1]. If the measured fault impedance is lesser than the impedance of the transmission line, it means that a fault exists on the transmission line between the relay and the fault point (vice-versa). This suggests that the distance protection method can reach a protection decision with the measured voltage and current at the relay location [8].

[9] added that achieving a distinct protection scheme will be possible through an

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integration of modern interconnected elements. The modern interconnected elements should lead to the high decision making and tripping time of the relay during fault condition.

## II. 2.0 DISTANCE RELAY PERFORMANCE

Distance relay performance is defined in terms of reach accuracy and operating time [11].. Reach accuracy is an assessment of the actual reach of the relay under practical conditions with the relay setting value in ohms [11]. Reach accuracy is commonly dependent on the level of voltage presented to the relay under fault conditions. The impedance measuring techniques employed in particular relay designs have great impact on the distance relay performance. The operating time of the relay can vary with fault current, fault position relative to the relay setting and the point at which the fault occurs [11]. Measured transient signal errors like that produced by the Capacitor Voltage Transformers (CVTs) or Saturated Current Transformers can adversely affect delay relay operation for faults nearest to the reach point [4]. For a fault at the reach point, this may be alternatively expressed in terms of source to line impedance ratio $\frac{Z_S}{Z_L}$ using the following expressions:

$V_R = I_R Z_R = I_R(Z_L + Z_S)$ where, $Z_R = Z_S + Z_L$ and $I_R = \frac{V_R}{Z_S + Z_L}$

(2.1)

where, $I_R$ = Relay current; $V_R$ = Relay Voltage; $Z_L$ = Line Impedance ; $Z_S$ = Source Impedance and $V$ = Total voltage [2].

## III. 3.0 MATERIALS AND METHOD

The following materials were collected as data from the Transmission Company of Nigeria (TCN), Benin and it was used to carry out the power flow study and the short circuit analysis for the 132kV transmission network. The data collected are: (i) Voltage Transformer rating of 132kV) (ii) Power Transformer whose rating is 90 MVA (iii) Current Transformer with a ratings of 400A was used(iv) Current Transformer ratio with a rating of 400/1A. (v) Resistance/kilometer of 0.222ohm/km (vi) Reactance/kilometer of 0.4281ohm/km. Neplan software was used to carry out the short circuit analysis and the power flow study of the distance protection network. The distance relays of the Delta region was examined using Neplan software as it concerns the conventional distance protection scheme. The case study has its network connecting Benin-Oghara, Oghara-Amukpe, Amukpe-Delta, Delta-Effurun, Delta-Ughelli and finally terminates at Ughelli transmission bus at the second layer of the network. To convert the primary impedance, $Z_{Pri.}$ to secondary impedance, $Z_{Sec.}$ in order to set a distance relay, the following expression was used in the form of an equation:

$$Z_{Sec.} = Z_{Pri.} * \frac{CTR}{VTR}$$

(3.1)

where, CTR and VTR are the current and potential transformer turn ratios, $Z_{Pri.}$ and $Z_{Sec.}$ are primary impedance and secondary impedance of the line [3].

$Z_1 = 0.2220 + j0.4189 = 0.474\Omega/km$ [6].

$Z_2 = 0.2450 + j0.5822 = 0.632\Omega/km$ [7].

$Z_0 = 0.4639 + j1.2986 = 1.379\Omega/km$ [5].

### 3.1 Neplan Software

Neplan is one of the major power system analysis software tools that can be used to analyze, simulate, plan and optimize electric power networks. Neplan has a Graphic User Interface (GUI) that is very user-friendly and it covers the three aspects of power systems. Neplan has a vast model library for thousands of network elements. It uses advance algorithms for dynamic simulations and it supports real time simulations of the models created in Matlab/Simulink directly. The reason why Neplan software was used was because users can develop elements in Matlab/Simulink and can simulate it using Neplan environment because it has a very effective import/export interface (verse-versa) Hence, Neplan software was chosen for computing fault current at different buses where the fault condition had occurred.

Table 3.1 gives a summary of the various transmission lines, line length, actual power and the circuit type used for this research. Power is transmitted from the Benin 330 kV to Oghara and from Oghara to Amukpe, Amukpe to Delta 1, from Delta 1 to Effurun and lastly from Effurun to Ughelli.

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Table 3.1: Line parameters for the 132 kV transmission network.

| Lines | Line Length (Km) | Actual Power (MVA) | Circuit Type |
|---|---|---|---|
| Benin-Oghara | 22.05 | 90 | Single Circuit |
| Oghara-Amukpe | 30.60 | 60, 30 - 60, 30/40 | Double Circuit |
| Amukpe-Delta 1 | 49.76 | 60, 30/40 – 90 | Single Circuit |
| Delta1- Effurun | 32.04 | 90 – 180 | Single Circuit |
| Effurun-Ughelli | 21.45 | 150 – 180 | Single Circuit |

Table 3.2 gives a summary of the calculated sequence impedances used for this research. The various positive, negative and zero sequence impedances across the Delta layer of the network were used for relay setting of the distance relay. The zero sequence impedances from Benin to Oghara, Oghara to Amukpe, Amukpe to Delta, Delta to Effurun and from Effurun to Ughelli were responsible for the mal-operation of the distance relay. The effect of the zero sequence impedances caused a change in the zero sequence current components, which in turn increases the fault current causing the mal-operation of the distance relay.

Table 3.2: The Sequence impedances of the conventional distance relays.

| Lines | Positive Sequence Impedance, $Z_1(\Omega)$ | Negative Sequence Impedance, $Z_2(\Omega)$ ($\Omega$) | Zero Sequence Impedance, $Z_0(\Omega)$ ($\Omega$) |
|---|---|---|---|
| Benin-Oghara | 10.45 | 13.94 | 30.41 |
| Oghara -Amukpe | 14.50 | 19.34 | 42.20 |
| Amukpe - Delta | 23.59 | 31.45 | 68.62 |
| Delta –Effurun | 15.19 | 20.25 | 44.18 |
| Effurun -Ughelli | 10.17 | 13.56 | 29.60 |

## IV. RESULTS AND DISCUSSION

For the investigation of the performance of the 132 kv delta region of the benin Transmission Network.

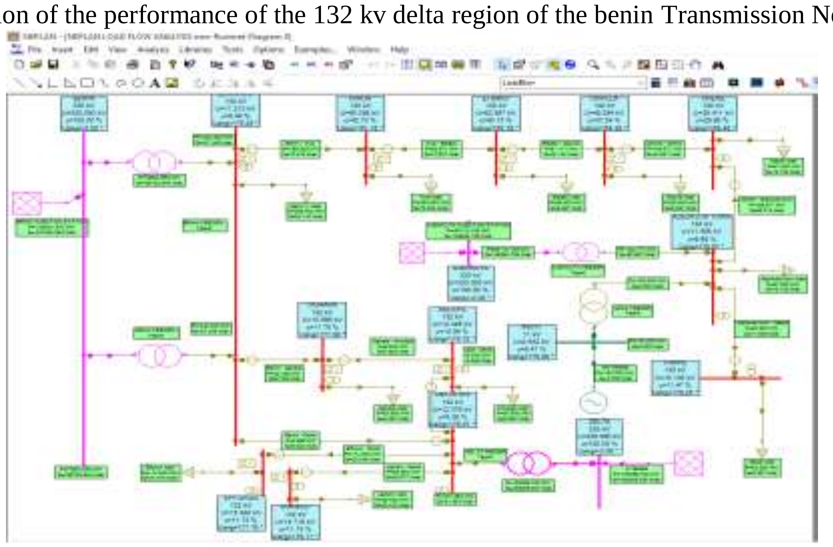

Figure 4.1: A snapshot of the power flow of the 132 kV buses in Neplan environment.

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Figure 4.1 captures the power flow from Benin 330 kV Mains through Delta feeder with a power of 240.383 MVA and the power that flows to the Oghara 132 kV bus bar was 22.168 MVA, which was transmitted to the Amukpe station, with a step-up power transformer to 34.832 MVA. There was a reduction in power to 30.445 MVA at Oghara-Amukpe line due to power losses on the line. The power then flows through the Amukpe-Delta line at 34.832 MVA. At Ughelli-Delta line, the power flow was 85.567 MVA. While, Effurun-Delta line had 114.238 MVA as its active power. The implication is that the power flow is unstable due to the fault current effect on the line.

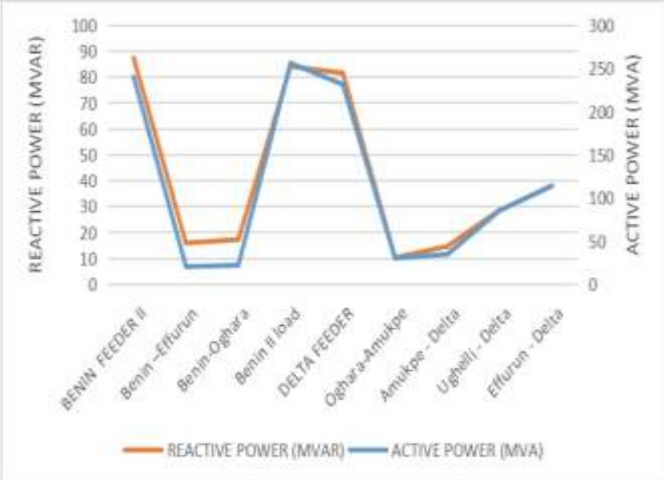


Figure 4.2: A graph of Active and reactive power.

From figure 4.2, there was a sudden decline in the reactive power at the Benin-Effurun and Benin-Oghara buses. The active power flows were very high at the Benin feeder II, Delta feeder and at Benin II load buses due to a drastic reduction in load demand. The Active Power and Reactive Power for Delta Side of the network from the various feeders on the line showed that the active power was 210MVA at peak at Delta feeder 1 but the reactive power was also high because of the high load demand on the feeder. The reactive power was 45MVA, which was lowest at Amukpe-Delta and Ughelli-Delta feeders due to a reduction in the load demand on the feeders. The current has influence on the both the active and the reactive power. Normally, when there is high power demand, the voltage decreases due to the voltage drop experienced. This condition made the current flow to increase as experienced at the Delta feeder and Delta feeder 11. At the Amukpe-Delta feeder, the current was very low, which connotes a high voltage at that feeder.

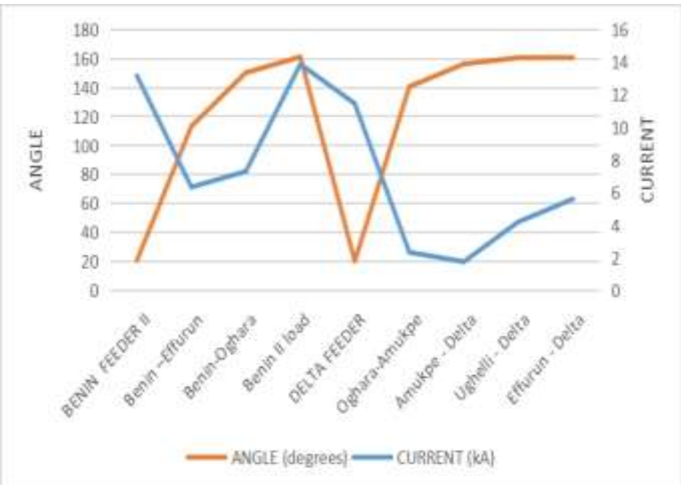


Figure 4.3: A graph of current and Phase angle.

From figure 4.3, there was a peak current of about 13.9 kA at the Benin II Load, Benin feeder I and Benin feeder II. The current values at these buses were affected by the changes in the angle of displacement between current and voltage in the buses. When there is a change in the current values, there will also be a corresponding change in voltages and angle of displacement across the various buses.

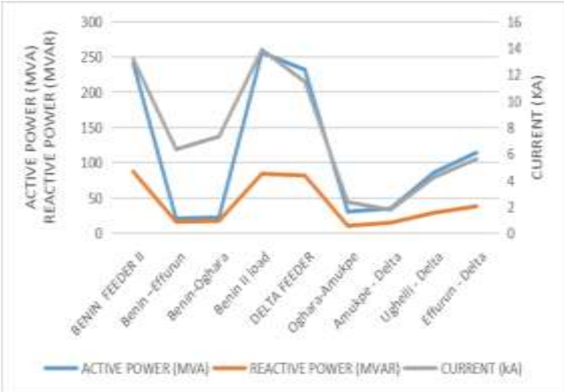

Figure 4.4: A graph of Active Power, Reactive Power and Current.

From figure 4.4, the active power and reactive power were noticed to be at peak at Benin II load, which was 256.213 MVA and 84.143 MVAR and at Delta Feeder, which was 231.6 MVA and 81.6 MVAR respectively.. The reactive power was used to provide information of the voltage level, which affects the current flow in the 132kV network. Also, the reactive power at Amukpe-Delta was about 14.693 MVAR, which was quite low amidst the Oghara-Amukpe feeder, which was the lowest due to a reduction in the load demand on the feeders. The current has influence on the both the active and the reactive power. Normally, when there is high power demand, the voltage decreases due to the voltage drop. This condition makes the current flow to increase as experienced at the Delta feeder and Delta feeder 11. At the Amukpe-Delta feeder, the current was about 3kA, which was very low connoting a high voltage at that feeder.

4.1 Short Circuit study of the faulted line for the 132kV Transmission network

A short circuit analysis of the 132 kV Benin Transmission Network was carried out at the different buses using Neplan software. A three-phase fault occurred at the Oghara-Amukpe transmission line. A yellow coloured line was used to indicate the location of the faults at the different buses and line.

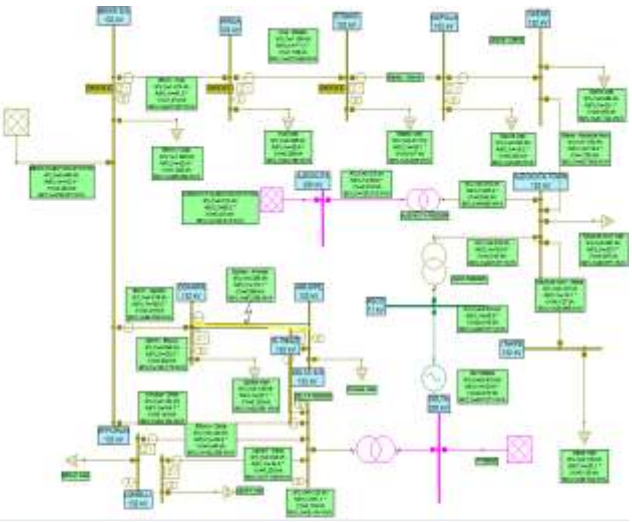
Figure 4.6: A Short Circuit Simulation Diagram of the Benin 132 kV Transmission Network with fault at Oghara-Amukpe line using Neplan Software.

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Figure 4.6 showed that Oghara-Amukpe bus was faulted, it was indicated with a yellow coloured line signifying an increment in short circuit current along the second layer coming from Oghara-Amukpe 132 kV transmission line to Delta 132 kV transmission line terminating at Ughelli 132 kV transmission line. The short circuit current that flowed through the Oghara-Amukpe transmission line increased from a nominal value to 2.891kA (2,891A), which was very high. This caused a high resistance effect on the transmission lines. The problems of over-load, over-voltage and over-current experienced on the transmission lines were seen as faults by the relays closest to the fault locations.

4.2 Oghara-Amukpe distance relay setting at the R-X plane.

For the zone one (1) setting of the conventional distance relay when there was no fault, the resistance (R) and the reactance (X) are 43.60 ohms and 82.10 ohms respectively from the R-X plane of the polygon characteristic as shown in figure 4.12. Hence, the impedance at no fault condition is 92.96 ohms. Only zone one (1) was activated; while other zones remained inactivated. During the three-phase fault, the circuit breaker opening time was 0.02 second.

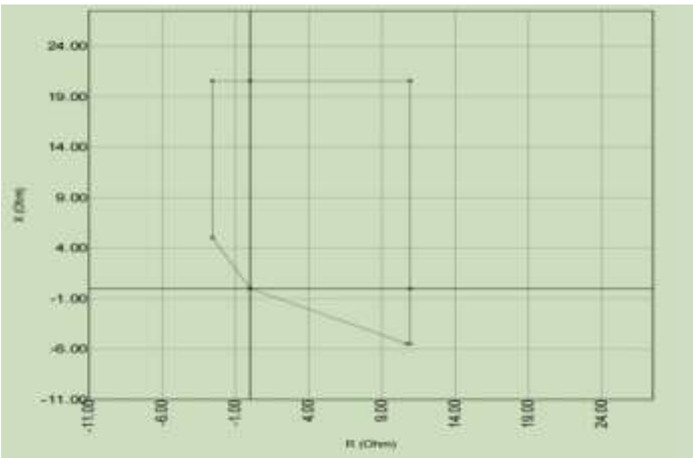


Figure 4.7:Characteristic impedance for Oghara Relay for three-phase fault at Oghara-Amukpe transmission line.

From figure 4.7, the Oghara-Amukpe transmission line for the zone 3 boundary, the resistance (R) was 10.81 ohms and the reactance (X) was 20.50 ohms when there was no fault. The arc resistance at no fault condition was zero ohm and the impedance was 23.18 ohms. When fault occurred, there was a change in resistance to 6.41 ohms and also a change in reactance, which decreased to a value of 11.50 ohms with an impedance of 12.91 ohms. The arc resistance during fault condition was 5 ohms.

Relay tripping time
NEPLAN®

| | ID | Name | From Node | Element | Type | Faulted Node | Trip Time | U L-E (RST) | AU L-E (RST) | Ik"(RST) | AIk"(RST) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | s | kV | ° | kA | ° |
| 1 | 797514 | DIS-Oghara | OGHARA | E-796077 | Distance Re | Oghara - Am | 0.100 | 26.044 | -3.15 | 1.790 | -65.17 |
| 2 | 797422 | DIS- Benin | BENIN S/S | E-796288 | Distance Re | Oghara - Am | 5.000 | 78.993 | -2.46 | 0.686 | -30.89 |

Figure 4.8: Relay Tripping time for three-phase fault at Oghara-Amukpe transmission line.

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From figure 4.8, the relay tripping time for the distance relay connecting Oghara-Amukpe side of the 132kV network was 0.1 second. This was due to high short circuit current value for the Oghara-Amukpe faulted node. The distance relay initiated a fast tripping action because of the high fault current at the Oghara-Amukpe bus.


Currents at fault locations
NEPLAN®

| | ID | Fault location | Un | Ik"(RST) | Alk"(RST) | Ik (RST) | Sk"(RST) | Fault | Method | Maximum | Network | CB delay time | SC duration | SC duration |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | kV | kA | ° | kA | MVA | type | | current | type | s | s | s |
| 1 | 796076 | Oghara - Amu | 132.000 | 2.891 | -70.42 | 2.891 | 661.027 | 3phase fa | Superpos. | | SING.FE | 0.020 | 1.000 | 0.020 |

Figure 4.9: Fault current for three-phase fault at Oghara-Amukpe transmission line.

From figure 4.9, the current at fault location at the Oghara-Amukpe 132 kV transmission bus was 2.891kA and the power that flows at the point of fault was 661.027 MW. The resistance of the Oghara-Amukpe line is 14.55 ohms. The implication of this result above is that the power and the short circuit current at the Oghara -Amukpe were very high, which caused a drop in the line voltage to 228.65 kV. This caused the relays at the Oghara-Amukpe axis not to respond to the clearance of the fault on that line.

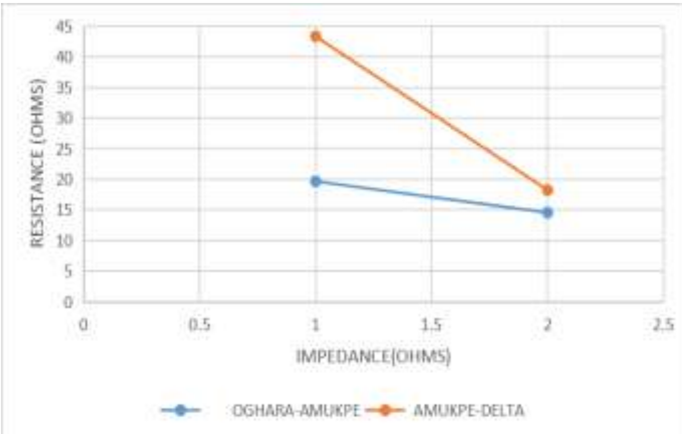


Figure 4.10: Resistance and Impedance of second layer of the transmission lines.

From figure 4.10, whenever there is fault along Oghara-Amukpe transmission line, the impedance value of the Oghara-Amukpe line was 2 ohms, which was very low when compared with other impedances due to the presence of fault current of 2.891kA on that line.

Tables 4.1, 4.2 and 4.3 explain the-power and current results at Oghara-Amukpe line after the three-phase fault had occurred at 60-80% fault distances with initial current and fault current of 1.790 kA and 2.891 kA with an initial power and power at three-phase fault of 661.027 MVA and 409.231 MVA respectively. The three-phase fault condition caused relays, $R_1$ and $R_2$ to operate or trip at 0.5 s and 0.10 s respectively. While, that of 81-99% fault distance at initial current and fault current of 1.790 kA and 2.822 kA with an initial power and power at three-phase fault of 661.027 MVA and 360.583 MVA respectively The three-phase fault condition caused relays, $R_1$and $R_2$ to operate or trip at 0.5 s and 0.10 s respectively.

Table 4.1: Initial Power and current after three-phase fault occurred at 60-80 % and 81-99 % fault distances at the Oghara-Amukpe line.

| Faulted line | Fault Distance (%) | Initial Current (kA) | Initial Power (MVA) |
|---|---|---|---|
| Oghara-Amukpe | 60-80 | 1.790 | 661.027 |
| Oghara-Amukpe | 81-99 | 1.790 | 661.027 |

Table 4.2: Power at three-phase fault and Fault current at 60-80 % and 81-99 % fault distances at the Oghara-Amukpe line.

| Faulted line | Fault Distance (%) | Fault Current (kA) | Power at three-phase fault (MVA) |
|---|---|---|---|
| Oghara-Amukpe | 60-80 | 2.891 | 409.231 |
| Oghara-Amukpe | 81-99 | 2.822 | 360.583 |

Table 4.3: Relay operating time at 60-80 % and 81-99 % fault distances at the Oghara-Amukpe line.

| Faulted line | Fault Distance (%) | Relay operating time (sec) | |
|---|---|---|---|
| | | $R_1$ | $R_2$ |
| Oghara-Amukpe | 60-80 | 0.5 | 0.10 |
| Oghara-Amukpe | 81-99 | 0.5 | 0.10 |

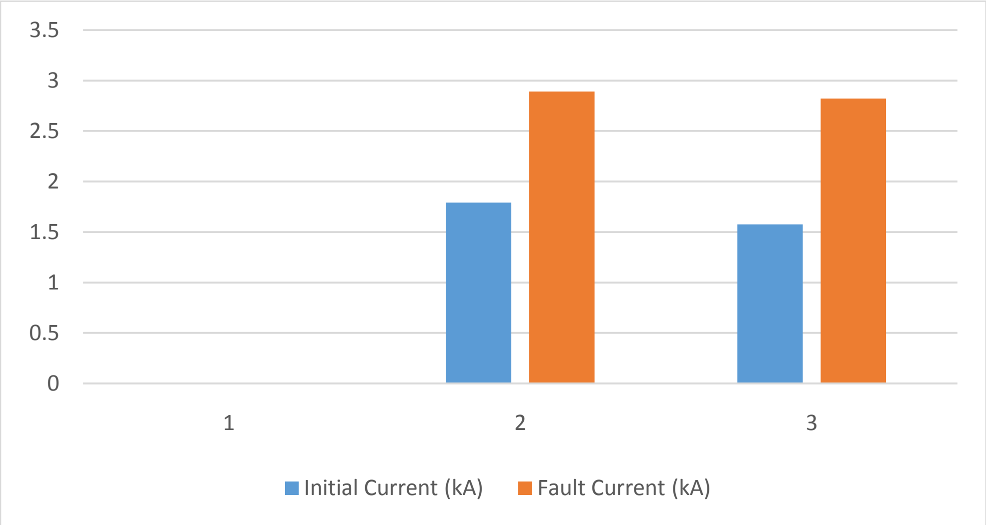


Figure 4.11: Initial current and fault current of Oghara-Amukpe line.

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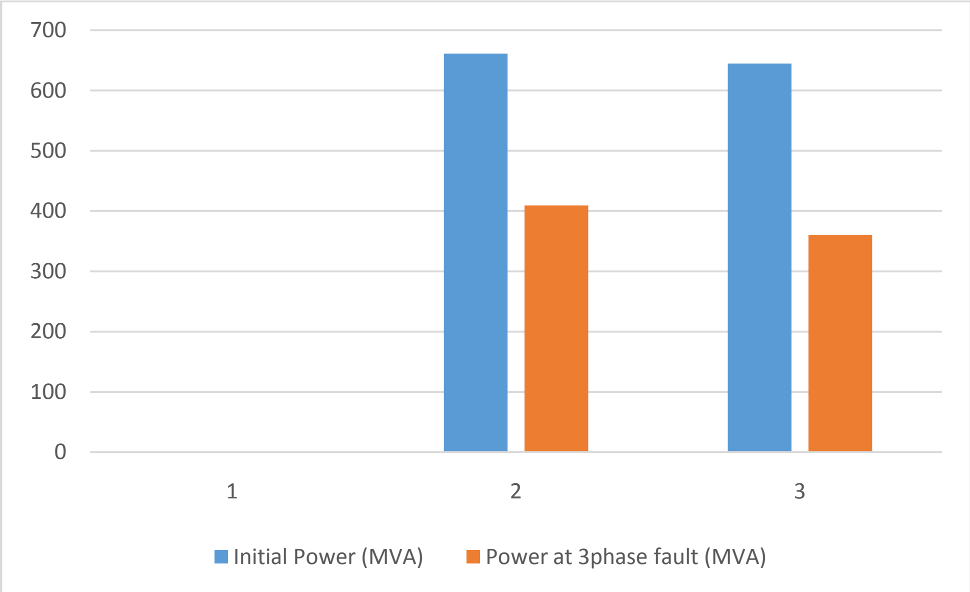


Figure 4.12: Initial power and power after three-phase fault occurred at Oghara-Amukpe line.

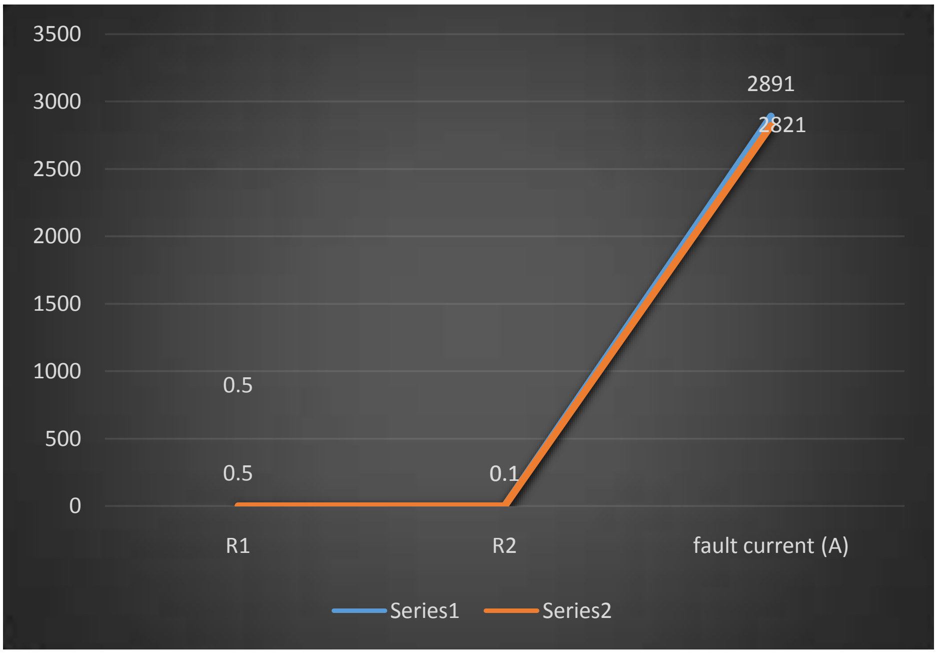


Figure 4.13: Relay operating time when fault occurred at Oghara-Amukpe line.

Figure 4.13 is a graph plotted to explain the relay operating time for relay 1 and Relay 2 at 0.5 s and 0.10 s at 60-80% fault distance. Also, the relay operating time for relay 1 and Relay 2 at 0.5 s and 0.10 second at 81-99% fault distance.

## 4.3 Performance of the Delta distance relays

In order to evaluate the performance of the Delta distance relay, the three-phase fault, the operating time of Relays $R_1$ and $R_2$ were analyzed. The results of the three-phase fault conditions as presented in Tables 4.4 and 4.5,which gave a summary of the performance of the distance relays for the Edo region being considered. The performance metrics used for the conventional distance relay was considered in terms of zone selection and operating time at which the conventional distance relays tripped due to the tripping action from the circuit breaker assigned to both relays.

Table 4.5: Relay 2 ($R_2$) performance during the three-phase fault.

| Fault Type (Three-phase fault) | Relay 2 ($R_2$) performance | | |
|---|---|---|---|
| | Fault Distance (%) | Zone Trip signal | Trip time (second) |
| ABC | 100 | Zone 2 | 0.19 |
| ABC | 81-99 | Zone 2 | 0.13 |
| ABC | 60-80 | Zone 1 | 0.10 |
| ABC | 40-59 | Zone 1 | 0.30 |
| ABC | 20-39 | Zone 1 | 0.40 |
| ABC | 0-19 | Zone 1 | 0.50 |

Table 4.4: Relay 1 ($R_1$) performance during the three

| -phase fault. F ault Type (Three-phase fault) | Relay 1 ($R_1$) performance | | |
|---|---|---|---|
| | Fault Distance (%) | Zone Trip signal | Trip time (second) |
| ABC | 0-19 | Zone 1 start | 0.40 |
| ABC | 20-39 | Zone 1 start | 0.50 |
| ABC | 40-59 | Zone 1 Middle | 0.30 |
| ABC | 60-80 | Zone 1 end | 0.10 |
| ABC | 81-99 | Zone 2 start | 0.13 |
| ABC | 100 | Zone 2 end/ Zone 3 | 0.10 |

V.

## VI. CONCLUSION

The distance relay performances for relays, $R_1$ and $R_2$ at fault distances (%) for the Oghara-Amukpe line of the Delta side of the 132 kV transmission network was not satisfactory because it had abnormal tripping time as a result of its delayed fault clearance at the instance of the three-phase fault. It is vital to conclude with the following findings which are as follow:

(1) For the Oghara-Amukpe line, the relay 1 ($R_1$) at zone one (1) during the three-phase fault had a delayed tripping time of 0.5 second and 0.10 second, which was also due to an non-instantaneous (unintentional) tripping action at 60-80% fault distance at zone one (1) boundary. Also, relay 2 ($R_2$) at zone two (2) had an instantaneous (intentional) tripping action of a delayed tripping time of 0.5 second and 0.10 second, which was due to an instantaneous (intentional) tripping action at 81-99% fault distance at zone two (2).

(2) For the Oghara-Amukpe line, the tripping action was instantaneous during the three-phase fault due to the slow tripping of relay 1 ($R_1$) and the fast tripping

of relay 2 ($R_2$) respectively. This caused the mal-operation of the conventional distance relays.

(3) There was high fault current magnitude of 2.891kA at the faulted line, which caused the low impedance experienced by the distance relays at the Oghara-Amukpe line.

(4) When fault occurred, there was a change in resistance and reactance to 6.41 ohms and 11.50 ohms, which had an impedance of 12.91 ohms when compared to the impedance of 23.18 ohms at no fault condition.

The relevance of this research is that the research has investigated the performance of the distance relays at the Delta region of 132 kV Transmission network and relevant findings were stated so as to further create a leeway for the improvement of the distance relay performance by harnessing other suitable methods. This could provide insight on enhancement of the distance relay settings through artificial intelligence methods.

Author Contributions

S .E. Igberaese: Conceptualization, Methodology, Software, Writing – original draft, Writing – review and editing. H. E. Amhenrior: Supervision, correction, review and editing.

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