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# Performance Determination and Limitations of the Conventional Impedance Relay Operation for Improving the Protection of Transmission Lines

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***Abstract*: This paper presented a survey of the performance and limitations of conventional impedance relay operation for improving the protection of transmission line. The fundamentals of transmission lines protection were considered many years ago but theoretical principles as well as the practical applications are still common topics of investigation in power system protection. Particular emphasis has been put in establishing the drawbacks inherent in conventional impedance relay used in most transmission line protection. The convention impedance relay is usually designed on the basis of fixed relay settings. The reach accuracy of the protective relay can therefore be affected by the different fault conditions as well as network configuration changes. The Statistical Package for Social Science (SPSS) analytical approach was used for the analysis of the relay performance. Historical field data provided by Transmission Company of Nigeria was used for the analysis. The result presented in this paper indicates that conventional impedance relay has an operation accuracy of 65.2% in terms of fault location which indicates the need for improvement as to reduce the outage duration. In view of the result, an artificial intelligent technique such as Neural Network, Fuzzy logic System , Genetic Algorithm or combination of any of the two techniques were recommended as an improved technique based on it perfect pattern recognition and decision making ability.**

***Key words: Distance relay, Impedance, protection Quality, Transmission line protection, Artificial intelligent and performance measurement.***

## 1. INTRODUCTION

The impedance types of distance relay protection scheme are mostly based on the calculation of certain AC quantities and their comparison with pre-defined thresholds [2]. This kind of relay relies purely on a 'hard' criterion where the settings required short circuit analysis to cover worst case fault conditions and coordinate the selectivity of each relay protection zone. The threshold based algorithm needs theoretical understanding and verification through the use of elaborate analysis tools. Even with the introduction of digital /numerical distance relay which forms part of the conventional relays in power system protection, no major breakthrough was made as far as security, dependability, speed of operation, accuracy and precision are concerned[7,9]. The reason simply is that the principle adopted by digital/numerical distance relay blindly reproduced the criteria known for decades[3].This paper briefly reviewed the performance and limitations in the operation of impedance type of distance relay in the protection of power system transmission lines and suggested the improvement that is required. After the general review of the principle and performance of operation of the impedance relay to establish in the theory, the limitations it has, a simple statistical analysis implored using a five years impedance relay historical operation data from New Haven, Enugu transmission station to show the practical performance inability of the relay in terms of accuracy and precision. The data presentation and result analysis are presented to establish the fact in this paper.

*Principles of impedance type of distance Relay*

Since the impedance of a transmission line is proportional to its length for distance measurement, it is appropriate to use a relay capable of measuring the impedance of a line up to a predetermined point (the reach point) .Such a relay is described as a distance relay and is designed to operate only for faults occurring between the relay location and the selected reach point [1], thus giving discrimination for faults that may occur in different line sections. The basic principle of distance protection involves the division of the voltage at the relaying point by the measured current. The apparent impedance so calculated is compared with a pre-determined impedance (normally the impedance of the circuit being protected multiplied by some factor), known as the reach point [4]. If the measured impedance is less than the reach point impedance, it is assumed that a fault exists the line between the relay and the reach point. The reach point of a relay is the point along the line impedance locus that is intersected by the boundary characteristic of the relay [2]. Since, this is dependent on the ratio of voltage and current and the phase angle between them; it may be plotted on an R/X diagram. The loci of power swings and load variations may be plotted on the same diagram and in this manner the performance of the relay in the presence of system faults and disturbances may be studied [6]. The relay algorithm is fixed by design. When the relay is installed in the system, the most important task is to determine the thresholds/ settings. The settings are obtained by comprehensive short circuit system studies in a pre- defined system operating condition. The relay principle is still dominantly used in most power industries all over the world and Nigeria in particular. Although, the relay hardware has advanced through the technologies of electromechanical, static solid state and to


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microprocessor, there are some obvious limitations associated with them which actually affects its accurate performance [8].

## 2. RELAY PERFORMANCE:

Distance relay performance is defined in terms of reach accuracy and operating time. Reach accuracy is a comparison of the actual ohmic reach of the relay under practical conditions with the relay setting value in ohms [2]. Reach accuracy particularly depends on the level of voltage presented to the relay under fault conditions. The impedance measuring techniques employed in particular relay designs also have an impact. Operating times can vary with fault current with fault position relative to the relay setting and with the point on the voltage wave at which the fault occurs [2, 5, and 11]. Depending on the measuring techniques employed in a particular relay design, measuring signal transient errors, such as those produced by capacitor voltage transformers or saturating CT's can also adversely delay relay operation for fault close to the reach point. It is usual for electromechanical and static distance relays to claim both maximum and minimum operating times. However, for modern digital or numerical distance relays, the variation between these is small over a wide range of system operating conditions and fault positions [6]. However, the lines are sectionalized in zones-zone 1, zone 2 and zone 3. Sometime it operates in over reached zones as backup protection for an adjacent transmission line and this gives rise to relay coordination to ensure selectively.

*Limitations of impedance type of relay*

- Since an approximation of steady state phasor of voltage and current are used for distance relay algorithm, other non-fault conditions that can cause low voltage and high current, such as power swing, under voltage and over voltage may cause the relay to misbehave [2]. The speed of operation of distance relay is also limited by its principle since it will take some time for calculated impedance to move from pre-fault load area to a stable fault area, hence it is robust and requires some energy for the movement.

- The signals that occurred during fault condition is a non-stationary signal containing fundamental frequency component , DC offset with damping, harmonics etc, the relay algorithm can only obtain an approximate value when extracting the fundamental frequency component[9,10] , since the information from unused components is lost, hence this situation may result in an inaccurate and imprecision in the representation of the fault signal, thereby causing false judgment of the relay which has adverse effects.

- In the calculation of certain fault parameters, a worst case system operating condition is applied and the compromise is made to cover worst case fault , but when the fault and system conditions deviates significantly from the expected, the relay settings may be ineffective, causing the relay to misbehave[5,2].

- For a large and robust power system, the calculation of setting the threshold is very complex and highly tedious. Hence, correct coordination needs to be made for the setting, to ensure selectivity of each relay in the system.

- Dependability (no missing operation) security demand (no false tripping) and the speed of operation are conflicting criteria for distance relay [7]. Meanwhile, there is no proper way to guarantee the dependability and security at the same time. The tradeoff is made during setting of the relay as to ensure balance of the two.

## 3. PERFORMANCE STUDY OF THE IMPEDANCE TYPE OF DISTANCE RELAY

Each fault tests the power system relays in the vicinity of the fault and present an opportunity to analyze the behavior of the entire protection system. The exploration of the existing Onitsha-New Haven 330KV transmission line relaying method based on hard criterion is carried out to show the drawback in its principle especially in fault location and why it contributes to longer and wider outages. Under fault condition on the transmission line, the fault current $I_1$ and fault voltage $V_f$ signals are fed into the relay software located at the both ends of the lines. The line parameters as calculated using the standard per unit measurement shown below (sourced from TCN) are programmed into the relay. Selectivity is to ensure steady power supply and minimum system interruptions.

- Transmission line impedance:
- positive sequence impedance Z.(p.u) = 0.0037+ j0.0292
  Zero sequence impedance $Z_0$(p.u) = 0.028 + j0.0868
  Transmission line length: 96KM
- Voltage sources: Sending end Voltage ($V_1$) = 330KV
  Receiving end Voltage ( $V_2$ )=330KV
  Capacity : Source capacity (MVA) = 630MVA
  Receiving Capacity (MVA) = 300MVA
- Frequency = 50HZ
- Positive sequence capacitance = 8nF/KM
- Zero sequence capacitance = 3.5nF/KM
- Conductor type / size :- Bison/350mm2 x 2 (bundle) single circuit
- Surge impedance :- 300ῃ
- Thermal rating :- 1360A
- C.T. Ratio :- 1600/1A
- V.T. Ratio :- 330000/110V = 3000V
- Existing Relay Type : Main 1 - SEL 421
  Main 2 - SEL 311L

Determining the Primary Values for the Setting of the Conventional Relay.

$Z_1$ = (0.0037 x j0.0292) x 1089 = (3.7026 + j31.7988) Ω
$Z_0$ = (0.0028 x j0.0868) x 1089 = (26.136 + j94.5252) Ω

Determining the Secondary Values for the Setting of the Conventional Relay.

$$\frac{CTR}{VTR} = \frac{1600}{3000} = 0.5333$$

$Z_1$ = (3.7026+ j31.7988) x 0.53331089 = (1.9747 + j16.9593) Ω = 17.0738 ∠83.36


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$Z_0$= (26.136+ j94.5252) x 0.5333 = (13.9392 + j50.4134) Ω = 52.3049 ∠74.54

$Z_1L = Z_1 = 17.0738\angle 83.36^{o}$

$Z_oL = Z_o = 52.3049\angle 74.54^{O}$

$Z_1$MAG =17.0738

$Z_1$ANG =83.36

$Z_O$MAG =52.3049$^{O}$

$Z_0$ANG =74.54$^{O}$

Setting of Conventional Relay

Considering an unsymmetric fault along the line, we calculate the voltage drop along the line

$$V_{f\,=}\ Z_L I_f \qquad (1)$$

Where $Z_L$ = Total line impedance from Sending to Receiving end.

K = fractional Distance of the line

The impedance $Z_k$ seen by the relay is computed as `

$$Z_k = \frac{V_f}{I_f} = KZ_L \qquad (2)$$

Equation (3.2) expresses the threshold or the impedance characteristic of the relay.

***Note:*** During normal system operation, the impedance seen by the relay is approximately equal to the load impedance that is much larger than the line impedance. For the faults within a distance K along the line, the measured impedance at the relay is

$$Z>Z_L = KZ_L \qquad (3)$$

For the zone setting calculation

$$Z_L< L \qquad (4)$$

This property is used to calculate the distance from the relay location to the fault.

The secondary value of I and V from the primary CT and VT are used for the setting.

$$Z_{sec} = \frac{I_{prim}/I_{sec}}{V_{prim}/V_{sec}} = Z_{prim} \qquad (5)$$

Where $\frac{I_{prim}}{I_{sec}}$ and are the transformation ratio of the I and V transformers respectively. So in order to cover a section of the line and to provide backup protection to remote sections, the three main protection zones are set up with the following calculation

Zone I

$Z_1MP = 0.9 \times Z_IL$ =0.9x17.0738 =15.366452

$Z_1PD$= Zone 1 times = 0

Zone II

$Z_2MP = 1.2 \times Z_IL$ =1.2x 17.0738
=20.488652

$Z_2PD$ = 350ms = 17.5 Cycles

Zone III

$Z_3MP$ = Zone 3 forward

1.2 (Protected line + Longest adjacent line)

1.2(Protected line + Onitsha-Benin

Performance Analysis of the Relay based on Calculation Setting: Based on the above calculation, the setting of the 'threshold setting' for the impedance type of distance relay were achieved and five years relay operational data results were collected on Onitsha- New Haven 330KV transmission line (T3H) from TCN, Enugu work centre in charge of the line Maintenance, Protection, Control and Metering.

Below are the raw data collected from TCN New Haven, Enugu Sub Region, on the operations of the existing electro-mechanical and numerical relay for five (5) consecutive years starting from 2011 to 2015 for analysis.

4. DATA PRESENTATION AND ANALYSIS

Table 4.1: Summary of the five years raw data (2011-2015) for the preliminary study of the performance of the conventional impedance relay operations. (Source from TCN New Haven, Enugu**)**

| Year | No | Month | Station | Name of 330KV feeder | Tripping Zone | Actual Zone | Cause of Outage |
|---|---|---|---|---|---|---|---|
| 2011 | 1 | Mar | New Haven | Onitsha 330KV | Zone 1 | Zone 1 | A-G |
| | 2 | Apr | New Haven | Onitsha 330KV | Zone 1 | Zone 1 | O/C |
| | 3 | May | New Haven | Onitsha 330KV | Zone 2 | Zone 2 | C-G |
| | 4 | May | New Haven | Onitsha 330KV | Zone 1 | Zone 2 | A-G |
| | 5 | June | New Haven | Onitsha 330KV | Zone 1 | Zone 1 | O/C |
| | 6 | July | New Haven | Onitsha 330KV | Zone 1 | Zone 2 | B-C |
| | 7 | July | New Haven | Onitsha 330KV | Zone 1 | Zone 1 | B-G |
| | 8 | Sept | New Haven | Onitsha 330KV | Zone 1 | Zone 1 | A-G |
| | 9 | Oct | New Haven | Onitsha 330KV | Zone 1 | Zone 2 | B-G |
| | 10 | Oct | New Haven | Onitsha 330KV | Zone 1 | Zone 1 | O/C |
| | 11 | Nov | New Haven | Onitsha 330KV | Zone 1 | Zone 2 | C-G |
| Total | | 11 | 11 | 11 | 11 | 11 | 11 |
| 2012 | 1 | Apr | New Haven | Onitsha 330KV | Zone 1 | Zone 3 | B-G |
| | 2 | Apr | New Haven | Onitsha 330KV | Zone 1 | Zone 1 | O/C |
| | 3 | July | New Haven | Onitsha 330KV | Zone 1 | Zone 1 | O/C |
| | 4 | Aug | New Haven | Onitsha 330KV | Zone 1 | Zone 3 | B-C |
| | 5 | Sept | New Haven | Onitsha 330KV | Zone 2 | Zone 2 | O/C |
| | 6 | Sept | New Haven | Onitsha 330KV | Zone 1 | Zone 1 | A-G |
| | 7 | Nov | New Haven | Onitsha 330KV | Zone 1 | Zone 2 | O/C |
| Total | | 7 | 7 | 7 | 7 | 7 | 7 |
| 2013 | 1 | Feb | New Haven | Onitsha 330KV | Zone 1 | Zone 2 | O/C |
| | 2 | Apr | New Haven | Onitsha 330KV | Zone 1 | Zone 1 | A-G |
| | 3 | Apr | New Haven | Onitsha 330KV | Zone 1 | Zone 1 | O/C |
| | 4 | May | New Haven | Onitsha 330KV | Zone 1 | Zone 1 | O/C |
| | 5 | May | New Haven | Onitsha 330KV | Zone 1 | Zone 1 | B-G |
| | | | | | | | |
| | | | | | | | |

| Year | No | Month | Station | Name of 330KV feeder | Tripping Zone | Actual Zone | Cause of Outage |
|---|---|---|---|---|---|---|---|
| | 6 | July | New Haven | Onitsha 330KV | Zone 3 | Zone 3 | B-C |
| | 7 | July | New Haven | Onitsha 330KV | Zone 1 | Zone 2 | O/C |
| | 8 | Aug | New Haven | Onitsha 330KV | Zone 3 | Zone 3 | C-G |
| | 9 | Sept | New Haven | Onitsha 330KV | Zone 1 | Zone 1 | O/C |
| | 10 | Sept | New Haven | Onitsha 330KV | Zone 1 | Zone 1 | B-G |
| | 11 | Oct | New Haven | Onitsha 330KV | Zone 2 | Zone 2 | A-G |
| | 12 | Nov | New Haven | Onitsha 330KV | Zone 2 | Zone 1 | B-G |
| | 13 | Nov | New Haven | Onitsha 330KV | Zone 1 | Zone 1 | O/C |
| Total | | 13 | 13 | 13 | 13 | 13 | 13 |
| 2014 | 1 | Mar | New Haven | Onitsha 330KV | Zone 1 | Zone 1 | B-G |
| | 2 | Apr | New Haven | Onitsha 330KV | Zone 1 | Zone 1 | B-C |
| | 3 | June | New Haven | Onitsha 330KV | Zone 1 | Zone 1 | O/C |
| | 4 | July | New Haven | Onitsha 330KV | Zone 1 | Zone 3 | A-G |
| | 5 | July | New Haven | Onitsha 330KV | Zone 1 | Zone 1 | B-G |
| | 6 | Oct | New Haven | Onitsha 330KV | Zone 1 | Zone 2 | C-G |
| Total | | 6 | 6 | 6 | 6 | 6 | 6 |
| 2015 | 1 | Feb | New Haven | Onitsha 330KV | Zone 1 | Zone 2 | B-G |
| | 2 | Mar | New Haven | Onitsha 330KV | Zone 2 | Zone 2 | A-G |
| | 3 | Apr | New Haven | Onitsha 330KV | Zone 1 | Zone 2 | C-G |
| | 4 | May | New Haven | Onitsha 330KV | Zone 1 | Zone 1 | O/C |
| | 5 | May | New Haven | Onitsha 330KV | Zone 2 | Zone 2 | O/C |
| | 6 | Aug | New Haven | Onitsha 330KV | Zone 1 | Zone 1 | B-G |
| | 7 | Sept | New Haven | Onitsha 330KV | Zone 1 | Zone 2 | O/C |
| | 8 | Oct | New Haven | Onitsha 330KV | Zone 3 | Zone 3 | O/C |
| | 9 | Dec | New Haven | Onitsha 330KV | Zone 1 | Zone 1 | A-G |
| Total | | 9 | 9 | 9 | 9 | 9 | 9 |
| Total | | 46 | 46 | 46 | 46 | 46 | 46 |



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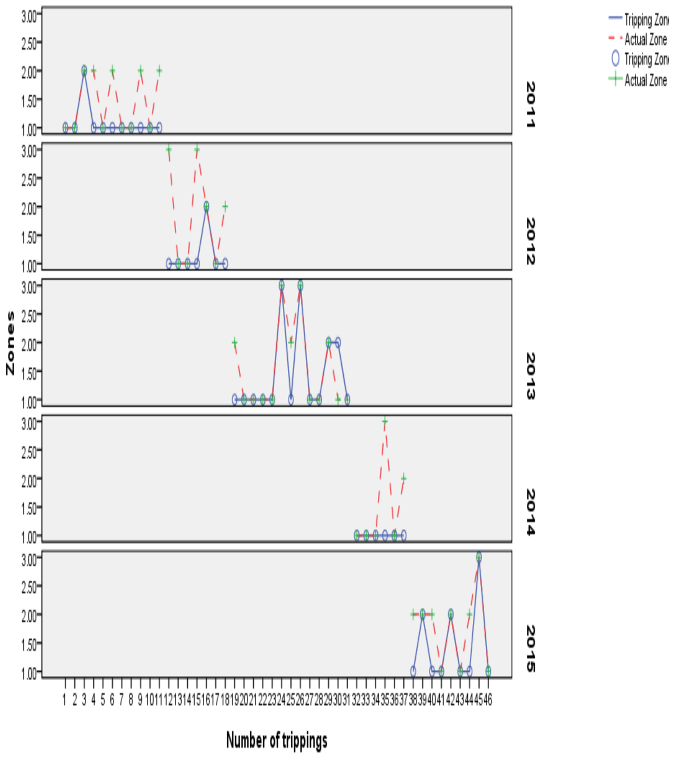


Fig 4.1: A five years (2011-2015) yearly analysis of the conventional impedance relay operations

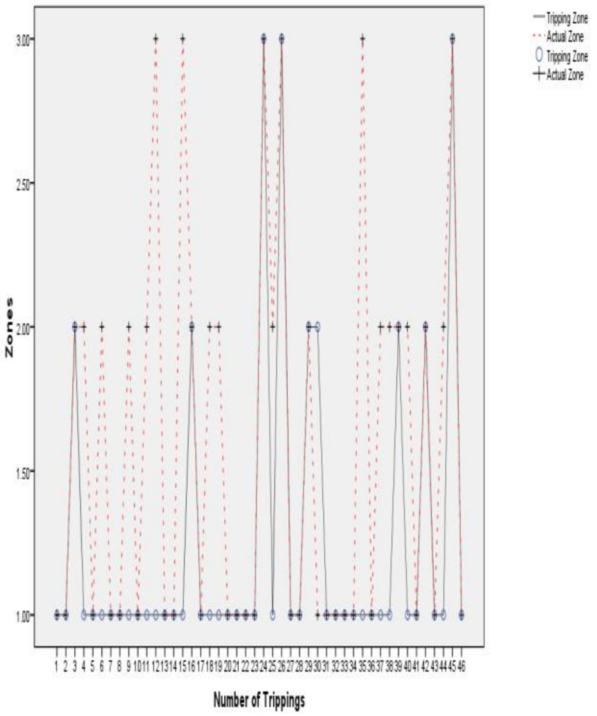


Fig 4.2: Schematic chart of Tripping Zone against actual location of fault (number of trippings) by the conventional Relay from 2011 to 2015 (cumulative)

Table 4.2: Cumulative Result of the five years analysis

| | | N | Percent |
|---|---|---|---|
| Sample | Accuracy | 30 | 65.2% |
| | Failure | 16 | 34.8% |
| Valid | | 46 | 100.0% |
| Excluded | | 0 | |
| Total | | 46 | |

From the performance evaluation using the Statistical Package for Social Science in the analysis, it shows that the conventional impedance relay has the accuracy of K=65.2% and a failure of 34.8% in location of faults.

| Capability Indices (Corrected Total) | K = 65.2% |
|---|---|

Result: From this analysis the operation of the conventional relay for the five (5) years 2011 to 2015 shows that it is 65.2% accurate in performance leaving a gap of 34.8% inaccuracy or imprecision, hence the need for improved performance.

Artificial Intelligent Protective Technique-An improvement in power system protection:

The artificial intelligent as improved technology, however has great capabilities and superior performances as compared with the conventional impedance relay. This is because its analytic methods are not based solely on deterministic mathematics but artificial intelligent learning. It has the following advantages over the conventional impedance relay operations.

Under certain system condition such as high impedance fault, variable source impedance and non-linear arc resistance, conventional distance protection relay may not operate efficiently but with AI application such limitations can be highly taken care of.

AI approach in power system can adapt dynamically to system operation conditions at high speed and solve the problem of reach and over reach.

AI is faster in operation, robust in nature and more accurate and more reliable.

AI does not require any communication link to retrieve remote end data but takes data from local end only.

AI improves training and testing of different network configurations until satisfactory performance is obtained.

AI has an adaptive nature which if employed zone settings and sensitive of protection can be increased to improve the system stability.

## 5. CONCLUSION

This paper is an effort to review the performance and limitation of conventional impedance relay and suggest an effective and efficient protective relaying technique considered to be a fast accurate and more precise technique in terms of artificial intelligence. The paper did not dwell on the improved technique but established that the conventional impedance relay has some limitations in its performance which militates against its accuracy and precision especially in fault location thereby prolonging outage duration. Because of these established limitations, an improvement on the relay algorithm


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is highly recommended to improve the reliability and security of the power system.

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