

Commissioning of the MICOM P443 Main 2 Distance Protection Relay on Ayede-Osogbo 330kV Transmission Line, Transmission Company of Nigeria, Ayede Sub-region

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ABSTRACT

A distance relay is a fundamental device that trips the circuit breaker in the event of a fault. Distance relays are one of the types of versatile relays used for distance protection, which depends on the distance between the feeding point and the fault. The relay, along with the circuit breaker are together used for the protection of transmission and distribution systems. The pick-up quantity is calculated based on the operating quantity. In the distance relay, the operating quantity is impedance. The relay operates based on the impedance of the transmission line. The impedance of the transmission line is calculated based on the fault location, the voltage at the time of the fault and the fault current. Relays are classified as mho relay, impedance relay and reactance relay- based on the distance of protection or based on the span of the transmission line. These relays are widely used, have several advantages and most reliable for all fault cases. The commissioning of the MICOM P443 Main 2 distance protection relay on Ayede-Osogbo 330kV transmission line at Transmission Company of Nigeria, Ayede sub-region was implemented so as to serve as a back-up for the Main 1 distance relay in order to provide full protection to the Ayede-Osogbo 330kV transmission line.

Keywords: Distance relay; distance protection; impedance; fault location; MICOM P443; Ayede-Osogbo 330kV transmission line

1.0 INTRODUCTION

Distance relaying is a form of protection against faults on long-distance power lines. Distance protection is the name given to the protection, whose action depends upon the distance of the feeding point to the fault. It is so named because it is actually able to estimate the physical distance between the relay's sensing transformers (potential transformers and current transformers) and the location of the fault. In this way, it is a more sophisticated form of fault detection than simple overcurrent protection. In engineering, a protective relay is a relay device designed to trip a circuit breaker when a fault is detected.

Microprocessor-based digital protection relays now emulate the original devices, as well as providing types of protection and supervision, impractical with electromechanical relays. Electromechanical relays provide only rudimentary indication of the location and origin of a fault. In many cases, a single microprocessor relay provides functions that would take two or more electromechanical devices. By combining several functions in one case, numerical relays also save capital cost and maintenance cost over electromechanical relays. The transmission and sub-transmission lines play an essential role in the distribution of electrical power to the end

users. They provide connections between the generation and distribution system. Transmission lines operate at voltage levels from 33kV to 330kV and are tightly interconnected for reliable operation. The theory and application of these protective devices is an important part of the education of a power engineer who specializes in power system protection. The need to act quickly to protect circuits and equipment often requires protective relays to respond and trip a breaker within a few thousandths of a second.

1.1 JUSTIFICATION/NEED FOR PROJECT

The key challenges of the transmission and sub-transmission line protection schemes are reliable detection, isolation of the faults from the healthy part of the system and provision of protection and security to the power system.

During my pupillage training at Transmission Company of Nigeria, Ayede sub-region, a backup distance protection relay was commissioned to replace a malfunctioned decommissioned one. The relay was giving protection to Ayede-Osogbo 330kV transmission line in case a fault arises along the transmission line. The transmission line needed to have adequate protection from damages caused by faults. Hence, the need to commission the MICOM P443 digital distance protection relay which replaced the malfunctioned decommissioned SIEMENS 7SA522.

1.2 PRELIMINARY STUDIES/INVESTIGATIONS

1.2.1 Distance relay theory and characteristics

Electrical protection plays an important role in the transmission of electricity. Distance protection, which forms part of electrical protection, is one of the most important types of protection to ensure the continuity of supply to the end users. Distance protection is more commonly used in protection of transmission lines.

The operation of the distance relay describes where the impedance of a transmission line is proportional to the line length, and uses voltage and current to calculate the apparent impedance. The distance relay compares and operates when the apparent impedance is less than the set reach point impedance. This type of protective device operates for faults between the relay and the reach point. Distance relays are actually double actuating quantity relays with one coil energized by voltage and the other coil by current. The current element produces a positive or pick-up torque while the voltage element produces a negative or reset torque. The relay operates only when the voltage-current ratio falls below a predetermined value (or set value).

During a fault on a transmission line, the fault current increases and the voltage at the fault point decreases. The voltage-current ratio is measured at the location of current transformers (CTs) and potential transformers (PTs). The voltage at PT location depends on the distance between PT and the fault. If the fault is nearer, measured voltage is lesser and if the fault is farther, measured voltage is more. Hence, such protection is called the distance protection or impedance protection. Distance protection is a non-unit type protection, the protection zone is not exact. The distance protection is high speed protection and is simple to apply. It can be employed as a primary or as well as backup protection.

Distance relays are used where overcurrent relaying is too slow and is not so selective. Distance protection relay principle differs from other forms of protection because their performance does not depend on the magnitude of the current or voltage in the protective circuit but it depends on

the ratio of these two quantities. Distance protection relay is very commonly used in the protection of transmission lines.

An important concept in protective relaying is that of protective zones. Protective relays exist to protect the power system from damage due to faults, and they do so by tripping circuit breakers to interrupt the flow of power to a fault. However, in the interest of maintaining power to customers, it is best for protective relays to only trip those breakers necessary to clear the fault, and no more. Thus, protective relays are designed to trip specific breakers to protect limited “zones” within the system.

The load flowing through the line appears as an impedance to the relay and sufficiently large loads (as impedance is inversely proportional to the load) can lead to a trip of the relay even in the absence of a fault. The impedance per kilometre is fairly constant in impedance-based distance relays. Therefore, impedance characteristics of the distance relay is analysed between the relay and the fault locations respectively.

In a three-phase power system, 10 types of faults are possible: three single phase-to-ground, three phase-to-phases, three double-phase-to-ground, and one three-phase fault. It is essential that the relays provided have the same setting regardless of the type of fault.

1.2.2 Digital (microprocessor-based) Protective Relays

Digital protective relays were in their infancy during the late 1960s. Digital protective relays have two main parts: hardware and software. A microprocessor-based digital protection relay can replace or emulate the functions of many discrete electromechanical relays in one device, simplifying protection, design and maintenance. The number of components is greatly reduced. The design and wiring is simpler and less costly to implement. These relays convert voltage and currents to digital form and process the resulting measurements using a microprocessor. Microprocessor-based relays also offer many features and functions in addition to base protection functions. The added benefits of simple scheme design and improved reliability make them a very attractive option. Each digital relay can run self-test routines to confirm its readiness and alarm if a fault is detected. Digital relays can also provide functions such as communications to supervisory control systems (SCADA) interface, monitoring of contact inputs, metering, waveform analysis, and other useful features. Digital relays can, for example, store multiple sets of protection parameters, which allows the behavior of the relay to be changed during maintenance of attached equipment. Digital relays also can provide protection strategies impossible to implement with electromechanical relays. This is particularly so in long-distance high voltage or multi-terminal circuits or in lines that are series or shunt compensated.

1.2.3 Classification of Distance Relays

Distance relays used for the protection of power circuits may be divided into two groups viz.:

- i) Definite distance relays and
- ii) Time-distance relays.

Definite distance relays operate instantaneously when the impedance (reactance or admittance) falls below a specified value. These relays may be of impedance, reactance or mho type.

Time-distance relays have the time of operation dependent upon the value of impedance (reactance or admittance) i.e., upon the distance of the fault from the relay point. A fault nearer

to the relay will operate it earlier than a fault farther away from the relay. These relays may be of impedance, reactance or mho type.

1.2.4 Types of Distance Relays

There are three general distance relay types; each is distinguished by its application and its operating characteristic. They are: (a) impedance relay, (b) admittance relay, and (c) reactance relay. The choice between impedance types, reactance type and mho type relays should be properly done with reference to their application to transmission line protection.

These are further explained below.

- a) Impedance relay: The impedance relay is non-directional and is used primarily as a fault detector. The impedance type relay is suitable for phase fault relaying for lines of moderate length. The arc affects the impedance relay more than the reactance relay but less than the mho relay. The impedance relay along with the directional unit can be made to change its characteristics and the modified impedance relay may resemble the reactance or mho unit. There is considerable overlap in the application of this relay.
- b) Admittance or mho relay: It is a high speed relay and is also known as admittance relay. It is also sometimes called an angle impedance relay. In this relay, operating torque is obtained by the volt-ampere element and the restraining torque is developed due to the voltage element. The admittance relay is the most commonly used distance relay. It is the tripping relay in pilot schemes and is used as backup relay in step distance schemes. Mho type relays are best suited for phase fault relaying for long lines and particularly where a severe synchronising power surge may occur. They are most sensitive of all the distance relays. The mho relay is reliable because it combines both the directional and distance measuring functions in one unit.
- c) Reactance relay: Reactance type relay is a high speed relay. It consists of two units—an overcurrent element developing positive torque and a current-voltage directional element which either aids or opposes the overcurrent element depending on the phase angle between the current and voltage. It is non-directional and is used to supplement the admittance relay as a tripping relay to make the overall protection independent of resistance. It is particularly useful on short lines where the fault arc resistance is the same order of magnitude as the line length. The ground distance relays must be unaffected by variation in fault resistance. For short line sections, reactance type relays are preferred for ground fault relaying because its reach is not affected by fault impedance (i.e., the arcing resistance) and more percentage of the line can be protected at high speed. The drawback of reactance relays, however, is that they are likely to operate undesirably on severe synchronising power swings at certain locations unless additional relay equipment is provided.

1.2.5 Applications of distance relay

The distance relay applications are:

- Most widely used to protect high voltage AC transmission lines and distribution lines over high AC voltages.
- They provide backup protection of AC voltages against the several faults in 3-phase, phase-to-phase, and phase-to-ground of distribution and transmission lines.

1.2.6 Zones of distance protection

In order to provide reliability, distance protection is divided into a number of zones. They are zones 1, 2 and 3.

A) Zone 1

This provides sufficient margin to account for non-zero fault impedance and other errors in relaying.

- Zone 1 is mainly intended to cover the entire length of the Protected Line Length and set to operate instantaneously i.e. with no intentional time delay.
- To avoid the loss of discrimination with the Zone 1 protection of the following line section, Zone 1 distance is set at 80 to 90% of the line and not 100%. Hence, it is called as an under-reaching element.
- This safety margin of 10 to 20% is kept for Relay/CT/PT errors, infeed/outfeed effects and inaccuracies in-line impedance parameters. Suppose the line is set at 100% of the protected line and the fault occurs on the adjacent line, but due to CT/PT errors, it may appear to the relay that the fault is on the protected line, thereby tripping the protected line, which is a wrong operation.

B) Zone 2

- Zone 2 is mainly intended to cover the remaining 10% to 20% of the protected line and provides backup for the adjoining lines (50% of the adjoining length).
- It set to cover remote end busbar and hence it is called an overreaching element. It is set at 150% of the protected line length or 100% of the protected line length plus the 50% of the shortest adjoining line length, whichever is the less. It is set in such a way, so that the Zone 2 of the adjacent lines do not overlap, so as avoid loss of discrimination.
- The operating time of Zone 2 is delayed by 15-45 cycle time, so as to be selective with Zone 1 of the Adjacent Line i.e. the Zone 1 relays that are supposed to trip get a chance to do their job first. For example, for a 330kV feeder, the operating time of the Zone 2 is about 500ms.
- Zone 2 should not overlap.
- In case of long line followed by short line, the above-mentioned formula may not give a margin against possible under-reaching. In such cases, Zone 2 can be set to cover 120% of the protected line length.

C) Zone 3

- Zone 3 is intended to give full backup to the adjoining line section.
- It is primarily intended to provide backup against external nucleated faults and hence set to cover the longest adjoining line.
- It covers full protected line length and full adjacent line plus the safety margin of 25%.
- Zone 3 covers, 100% of the line length plus the 100% of the longest adjacent line length plus a 10 km of additional length is considered, to clear the bus fault at the remote end.
- The operating time of zone 3 should be slightly more than the Zone 2 operating time. For example, a 330kV line has about 600ms as its operating time.
- In case of long heavily loaded line, the Zone 3 settings should be checked for possible load encroachment.

1.3 MODE OF OPERATION CONSIDERATIONS

A minimum of two zones are necessary for primary protection because of the impossibility of determining if the fault is within or is outside the line section. Both zones operate instantaneously, but one (Zone 2) is delayed by the current transformer, to provide coordination.

A fixed timer is used. It has been customary over many years to apply a forward third zone to provide backup protection for the remote line(s). It has been a common practice to use separate distance units for the several protection zones. This is in contrast with distance relays that use a single distance-measuring unit initially set for Zone 1 reach. If the fault persists, the reach is extended by switching to Zone 2 after T2 (time delay for Zone 2), then after T3 (time delay for Zone 3) to Zone 3. Both designs provide good protection. Separate units provide the comfort of redundancy because, for faults in the Zone 1 primary reach area, all three distance units provide redundancy. Also one should note that Z2 also provides backup protection to a part of the adjacent line. Therefore, one would desire that Z2 should be extended to cover as large a portion of adjacent line as possible. Typically, Z2 is set to reach 50% of the shortest backup line provided. Since, backup protection has to be provided for entire length of remote line, a third zone of protection, Z3 is used.

On long lines, where large mho operating circles can include the load areas, the restrictive characteristics are used. They provide a long reach in the fault area, with quite a restricted reach in the load areas. The operating circles must be set such that they do not operate on any system swings from which the system can recover. Such swings occur after a system disturbance, such as faults, sudden loss of generation or load, or from switching operations. These swings may also require application of the restricted operating characteristics.

Zone 1 at each end of the line provides the most desirable protection—simultaneous high-speed operation for the middle 80% of the line section.

This can be increased to 100% only with pilot relaying. Backup protection is ideal and seldom obtainable. In practice, most buses have multiple lines of different lengths and with power sources at their remote ends. This problem is multiplied with other lines of different lengths extending from the bus. However, the reach will not be as far as indicated because of the infeed effect. Fault current from other lines will cause relays to underreach as a result of the fault contributions from other lines connected to the bus. Setting of the relays for the apparent impedance value has the danger of overreaching and miscoordination when the infeeds are removed or changed by system operation. The infeed term can be quite large and also variable when a large part of the current fault is supplied by other circuits. The relay underreach will approach the remote bus, but not quite reach it, so primary protection is not inhibited.

Undesired operation of Zone 3 distance relays applied for remote backup protection during major system disturbances has caused the magnitude of the scope of such disturbances to be expanded. Large ohmic settings had been typically applied to the Zone 3 relaying, in order to obtain the desired backup protection. Power swings and low-voltage conditions that often exist during system disturbances result in the impedance seen by the Zone 3 relay to be within its operating characteristic for a sufficient length of time for it to initiate a trip command. Such experiences have resulted in utilities restricting the use or reach applied to Zone 3 relaying.

1.4 STANDARDS AND SPECIFICATIONS

The MICOM P443 distance protection relay has the ANSI/IEEE number code designation for distance relaying as 21. Below is its specifications:

1.4.1 RATINGS

AC Measuring Inputs

Nominal frequency: 50 and 60Hz (settable)

Operating range: 45 to 66.3Hz

Phase rotation: ABC or ACB

AC Current

Nominal current (I_n): 1 and 5A dual rated. (1A and 5A inputs use different transformer tap connections).

Nominal burden per phase: $< 0.15VA$ at I_n

Thermal withstand: continuous $4 I_n$ (for 10s: $30 I_n$; for 1s: $100 I_n$)

Linear to $64 I_n$ (non-offset AC current).

AC Voltage

Nominal voltage (V_n): 100 to 120V phase-phase.

Nominal burden per phase: $< 0.02VA$ at V_n .

Thermal withstand: continuous $2V_n$ for 10s: $2.6V_n$

AC Measurement Range

- The device shall be suitable for power systems operating at 50 and 60Hz.
- The operating range for the network frequency shall be from 45 to 65Hz.
- The relay shall be suitable for current transformer secondary ratings of 1A and 5A and shall be selectable, as required. The standard and sensitive current transformer inputs shall have a continuous rating of 4 times the rated current and a short time thermal withstand capability of 100 times the rated current for 1 second.
- The dynamic range for the standard CT inputs shall be 16 times rated current and the sensitive current inputs shall be 2 times rated current.
- The current inputs shall have automatic CT shorting when the analogue module is removed, to enhance the safe working environment of technicians and relay engineers.
- The voltage transformer inputs shall be rated for 100/120V or 380/480V AC and shall have a continuous rating of 2 times the rated voltage. The inputs shall have a short time thermal withstand capability of 2.6 times the rated voltage for 10 seconds.

1.4.2 POWER SUPPLY

Auxiliary Voltage (V_x)

Three ordering options:

(i) V_x : 24 to 32V DC

(ii) V_x : 48 to 110V DC,

(iii) V_x : 110 to 250V DC, and 100 to 240V AC (rms).

Operating Range

(i) 19 to 38V (DC only for this variant)

(ii) 37 to 150V (DC only for this variant)

(iii) 87 to 300V (DC), 80 to 265V (AC).

With a tolerable ac ripple of up to 12% for a DC supply, per IEC 60255-11: 1979.

Nominal Burden

Quiescent burden: 11W. (Extra 1.25W when fitted with second rear Courier)

Additions for energized binary inputs/outputs:

per opto input: 0.09W (24 to 54V), 0.12W (110/125V), 0.19W (220/120V)

Per energized output relay: 0.13W

Power-up Time

Main Processor including User Interface and front access port $< 25s$.

Ethernet Communications <120s.

Power Supply Interruption

Per IEC 60255-11: 1979

The relay will withstand a 20ms interruption in the DC auxiliary supply, without de-energizing.

Per IEC 61000-4-11: 1994

The relay will withstand a 20ms interruption in an AC auxiliary supply, without de-energizing.

Battery Backup

Front panel mounted.

Type ½ AA, 3.6 V Lithium Thionyl Chloride (SAFT advanced battery reference LS14250).

Battery life (assuming relay energized for 90% time) >10 years.

Field Voltage Output

Regulated 48V DC

Current limited at 112mA maximum output

1.5 METHODOLOGY AND DESIGN CALCULATIONS

The MICOM P443 relay was used as a replacement for the faulty SIEMENS 7SA522 relay. At first, simulation and lab testing were carried out before eventually taking the relay to the switchyard. The settings of the MICOM P443 relay was done on a computer through a software specifically programmed for the relay called 'MICOM S1 Agile'. All necessary parameters were input using the software. Afterwards, connections were done at the back of the relay using 2.5mm² protection cables. These connections were carried out using a circuit diagram provided by the manufacturer which came with the instruction manual of the relay. The circuit diagram served as a guide to connect the cables the way they should be connected. The relay was powered using a DC power source that was controlled with a Miniature Circuit Breaker (MCB) with a rating of 2A. After the connections were properly done, the computer and relay were connected together using an Ethernet cable. All the settings previously done in the MICOM S1 Agile software were transferred to the relay via the Ethernet cable.

The already set relay was connected through the computer to a secondary current relay injection test kit called OMICRON CMC 356 using RJ 45 (internet) cable which was able to communicate with the computer through a software called OMICRON Test Universe 4.2.0 Quick CMC. This secondary current relay injection test kit was used to test if the relay was in good condition and properly set.

1.5.1 DESIGN CALCULATIONS

Ayede-Osogbo 330kV line (H2A) CCT relay settings. The calculations for these settings are shown below:

1.

$$Z_1 = 0.0041 + j0.0349 \text{ pu}$$

$$Z_0 = 0.0291 + j0.104 \text{ pu}$$

$$CT \text{ Ratio} = 750/1 \text{ A}$$

$$VT \text{ Ratio} = 330,000/110 \text{ V}$$

Line length = 115km

2.

$$Z_b = \frac{V^2}{R} = \frac{(330)^2}{100} = 1,089 \Omega$$

$$Z_{1(Pri)} = 0.0041 + j0.0349 \times Z_b$$

$$Z_{1(Pri)} = 4.4649 + j38.0061 \Omega$$

$$Z_{1(Sec)} = Z_{1(Pri)} \times \frac{CT}{VT}$$

$$Z_{1(Sec)} = 4.4649 + j38.0061 \times \frac{750}{1} \times \frac{110}{330,000}$$

$$Z_{1(Sec)} = 1.1162 + j9.5015 \Omega$$

$$Z_{1(Sec)} = 9.5668 \angle 83.29^\circ \Omega$$

3

$$Z_{0(Pri)} = 0.0291 + j0.104 \times Z_b$$

$$Z_{0(Pri)} = 0.0291 + j0.104 \times 1089 \Omega$$

$$Z_{0(Pri)} = 31.6899 + j113.256 \Omega$$

4.

$$Z_{0(Sec)} = Z_{0(Pri)} \times \frac{CT}{VT}$$

$$Z_{0(Sec)} = 31.6899 + j113.256 \times \frac{750}{1} \times \frac{110}{330,000}$$

$$Z_{0(Sec)} = 7.9225 + j28.314 \Omega$$

$$Z_{0(Sec)} = 29.4105 \angle 74.36 \Omega$$

5.

Arc Resistance (Pri) = 6 Ω

$$R_{Arc(Sec)} = 6 \times \frac{CT}{VT}$$

$$R_{Arc(Sec)} = 6 \times \frac{750}{1} \times \frac{110}{330,000}$$

$$R_{Arc(Sec)} = 4.5 \Omega$$

Tower Resistance = R_{tower}

$$= 6 \times \frac{CT}{VT}$$

$$= 6 \times \frac{750}{1} \times \frac{110}{330,000}$$

$$R_{tower} = 4.5 \Omega$$

MHO Settings

1 Phase Fault

Zone 1 = 90% of protected line

$$= 0.9 \times Z_{1(Sec)}$$

$$= 0.9 \times 9.5668$$

$$Zone 1 = 8.61012 \angle 83.29^\circ \Omega$$

Zone 2 = 100% of protected line + 50% of shortest line (Ganmo)

$$Z_{1(ganmo)} = \frac{9.5668}{115} \times 78$$

$$= 6.489 \angle 83.29^\circ \Omega$$

$$Zone2 = 9.5668 + (0.5 \times 6.489)$$

$$= 9.5668 + 3.2445$$

$$= 12.8113 \angle 83.29^\circ \Omega$$

Zone 3 = 100% protected line + 50% of next longest line

$$= 9.5668 + \frac{50}{100} \times 41.9428$$

$$= 9.5668 + j20.971 \Omega$$

$$= 30.5378 \angle 83.29^\circ \Omega$$

$$K_0 = \frac{\frac{1}{3}(Z_0 - Z_1)}{Z_1}$$

$$K_0 = \frac{\frac{1}{3}(29.4015 - 9.5668)}{9.5668}$$

$$K_0 = \frac{6.6115}{9.5668}$$

$$K_0 = 0.691$$

$$K_{0(angle)} = -13.186^\circ$$

2 Ground Faults (Quad)

$$\mathbf{Zone 1} = R_{oZone} + \frac{2}{3} \times R_{1Zone} + R_{tower}$$

$$= (0.9 \times 7.9225) + \left(\frac{2}{3} \times 0.9 \times 1.1162\right) + 4.5$$

$$\text{Zone 1}_{(Ph-G)} = 12.2999 \Omega$$

$$\mathbf{Zone 2} = R_{oZone} + \frac{2}{3} \times R_{1Zone} + R_{tower}$$

To get the Z_0 of Ganmo:

$$Z_{0sec} = \frac{7.9225 + j28.314}{115} \times 78$$

$$Z_{0sec} = 5.3735 + j19.2043 \Omega$$

$$Z_{0sec} = 19.942 \angle 74.37^\circ \Omega$$

$$\text{Zone 2} = (0.5 \times 5.3735) + \left(\frac{2}{3} \times 0.7582\right) + 4.5 + 7.9225$$

$$\text{Zone 2} = 2.6867 + 0.5054 + 4.5 + 7.9225$$

$$\text{Zone } 2_{(\text{Ph-G})} = 15.6116 \Omega$$

$$\begin{aligned} \text{Zone } 3 &= 7.9225 + 0.5R_{0\text{Zone}} + \frac{2}{3} \times R_{1\text{Zone}} + R_{\text{tower}} \\ \text{Zone } 3 &= 7.9225 + (0.5 \times 34.415) + \left(\frac{2}{3} \times 3.568\right) + 4.5 \end{aligned}$$

$$\text{Zone } 3 = 7.9225 + 17.2075 + 2.379 + 4.5$$

$$\text{Zone } 3_{(\text{Ph-G})} = 32.009 \Omega$$

1. **Zone 3 (Reverse) = 20% of Zone 1 settings (Mho Settings)**

$$\begin{aligned} &= 0.2 \times 8.61012 \\ &= 1.7220 \Omega \end{aligned}$$

2. **Zone 3_(Ph-G) = 20% of R_{oZone} + $\frac{2}{3}$ × R_{1Zone} + R_{tower} (Quad Settings)**

$$\begin{aligned} &= (0.2 \times 0.9 \times 7.9225) + \left(\frac{2}{3} \times 0.9 \times 1.1162\right) + 4.5 \\ &= 1.42605 + 0.6697 + 4.5 \\ &= 6.5958 \Omega \end{aligned}$$

Z_b = Base impedance (initial impedance), Z_1 = positive sequence per unit impedance, Z_0 = zero sequence per unit impedance, $Z_{0(\text{pri})}$ = zero sequence impedance in primary, $Z_{0(\text{sec})}$ = zero sequence impedance in secondary, $Z_{1(\text{pri})}$ = positive sequence impedance in primary, $Z_{1(\text{sec})}$ = positive sequence impedance in secondary, $R_{\text{arc}(\text{sec})}$ = secondary arc resistance, R_{tower} = tower resistance, K_o = Ground compensation factor, $R_{1\text{Zone}}$ = resistance on Zone 1, Zone 1_(ph-G) = Zone 1 phase-to-ground, Zone 2_(ph-G) = Zone 2 phase-to-ground, Zone 3_(ph-G) = Zone 3 phase-to-ground

1.6 DRAWINGS

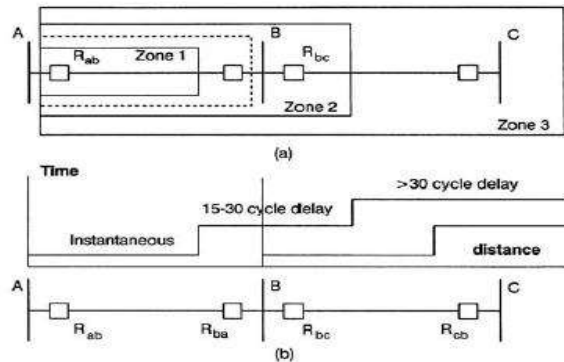


Figure 1: Three-zone step distance relaying to protect 100% of a line and backup the neighbouring line

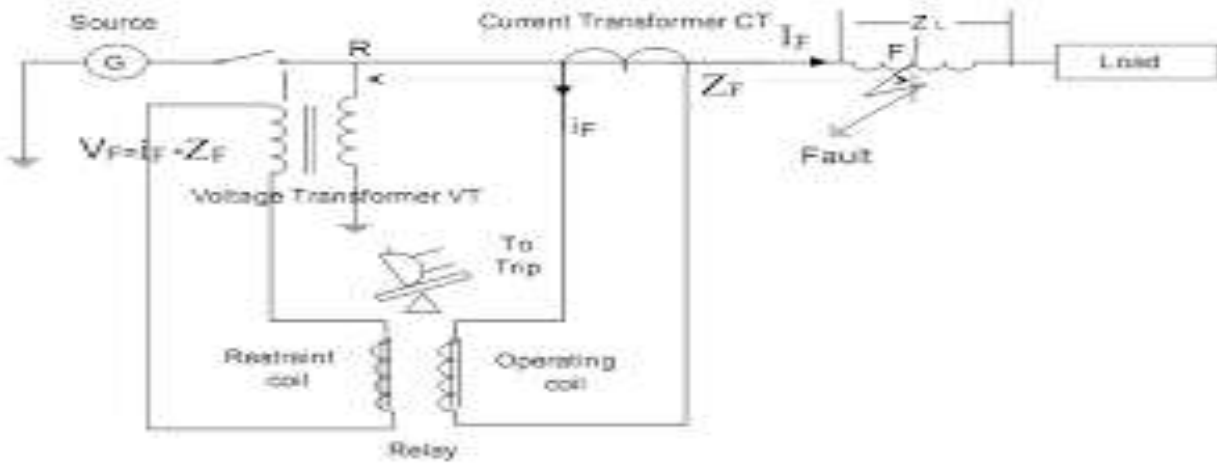


Figure 2: Distance Relay Operation

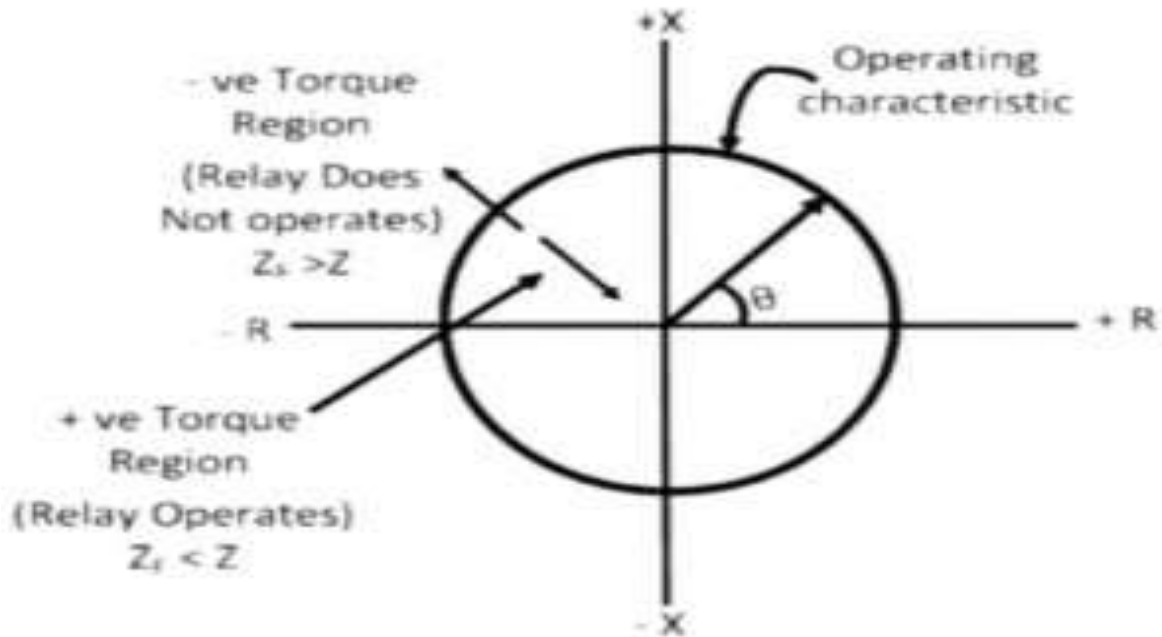


Figure 3: Operating characteristics of an impedance relay on an R-X plane

1.7 PREPARATION OF BILL OF ENGINEERING MEASUREMENT AND EVALUATION (BEME)

NAME OF PROJECT: THE COMMISSIONING OF THE MICOM P443 MAIN 2 DISTANCE PROTECTION RELAY ON AYEDE-OSOGBO LINE, TRANSMISSION COMPANY OF NIGERIA, AYEDE SUB-REGION
PROJECT STATUS: BoQ
COMPLETION DATE: JANUARY 2021

S/N	ITEMS	BoQ QUANTITY	2021 UNIT RATE (₦)	TOTAL COST (₦)
1	2A Miniature Circuit Breaker (MCB)	1	4,500.00	4,500.00
2	19 core 2.5mm ² armoured cable	4 metres	1,350.00	5,400.00
3	MICOM P443 relay	1	2,000,000.00	2,000,000.00
	GRAND TOTAL:			2,009,900.00

Table 1: Bill of Engineering Measurement and Evaluation (BEME) for the commissioning of the MICOM P443 distance protection relay

1.8 TEST AND CALCULATIONS

1.8.1 Distance Relay Testing and Its Procedure

The distance relay testing is required to check the settings for the protection relay, configuration of the relay, installation, testing and commissioning of the entire device for optimum protection. As the distance relay is used for universal short-circuit protection, its operating condition depends on the electrical quantities measurements like voltage and current, impedance value evaluation for fault that is proportional to the distance between the relay and the point of fault occurs.

It was ensured that all the 3 zones of the protection relay were set properly. Zone 1 was set for instantaneous tripping mode in forwarding direction. Zone 2 was set for over-reaching with a time delay (single) in the forward direction. Zone 3 was set for over-reaching with time-delay in the double mode for the reverse direction. It was ensured that all the remaining protection operating modes were turned off while testing any protection mode. It was also ensured and checked that all the connections of Potential Transformer (PT), Current Transformer (CT) and transmission line links were connected properly.

The following tests were carried out: Phase-Ground fault test, Zone protection test, multiple zone test, Directional Earth Fault (DEF) test, overcurrent setting test, the circuit breaker test and line breaker test.

Zone Protection Test

Each of the Zones-Zones 1, 2 and 3 were tested for and they responded satisfactorily.

Multiple Zone Test

All the 3 zones were tested simultaneously and they all responded. This test confirmed that all the 3 zones were working well. This test was also used to stress up the relay so as to determine how much it can withstand high stress.

Directional Earth Fault (DEF) Test

To test for DEF, DEF was enabled on the ‘MICOM S1 Agile’ software. After doing this, the current of a particular phase was increased and the voltage was reduced. This was done so that the DEF LED can come on.

Overcurrent Setting Test

To test for this, all voltages were be set to normal values but the current settings were be set to values higher than normal. When this was done, the time multiplier setting was done and the lowest time setting was picked for this test.

Circuit breaker test

The circuit breaker test was done and the circuit breaker responded satisfactorily to this test.

Line breaker test

The line breaker test was carried out and the result was satisfactory.

All these tests carried out were done through the MICOM S1 Agile software which is the programmable software provided by the manufacturer that synchronises with the relay.

OTHER PROTECTION SETTINGS TESTS RESULT ON AYEDE-OSOGBO 330kV LINE

1) Directional Earth Fault (DEF) Test

Applied Voltage (Volts)	Applied Current (Amperes)	Time (s)
40	1.00	1.7660
40	0.50	6.0240
40	1.50	0.0497

2) Backup overcurrent test

Applied Voltage (Volts)	Applied Current (Amperes)	Time (s)
63.5	3	4.284
63.5	4	2.520
63.5	5	1.909

3) Switch On To Fault (SOTF) Test

Applied Voltage (Volts)	Applied Current (Amperes)	Time (ms)
10.0	5.0	56.10
63.5	0.0	56.10
63.5	5.0	56.10

1.9 ANALYSIS OF RESULTS AND COMMISSIONING

After the above tests were carried out and passed, the relay was taken to the switchyard and an application for protection guarantee was made, which was granted. An armoured 19 core 2.5mm² cable of length 4 metres was laid in the switchyard and passed from the energy source into the relay through a 2A MCB which was used to power the relay in the switchyard. Thereafter, necessary connections were done and cables were terminated. All the simulation tests previously done were confirmed and the relay was eventually energized and commissioned.

COMMISSIONING PARAMETERS & VALUES

1) Measured Current

$$I_R=0.390A$$

$$I_Y=0.373A$$

$$I_B=0.382A$$

$$I_N=0.015A$$

2) Measured Voltage

$$V_{RY}=108.0V$$

$$V_{YB}=107.0V$$

$$V_{BR}=105.0V$$

$$V_{RN}=61.80V$$

$$V_{YN}=61.10V$$

$$V_{BN}=61.20V$$

RELAY Current (Amps)	Voltage (kV)
$I_A=289$	$V_{AB}=319.5$
$I_B=277.6$	$V_{BC}=318.9$
$I_C=282.1$	$V_{CA}=316.7$
$I_N=6.096$	$V_{AN}=183.4$
	$V_{BN}=184.6$
	$V_{CN}=183.1$

1.9.1 Problems encountered and their solutions

1) During testing, a major problem was encountered. The relay kept on displaying 'voltage fail'. In troubleshooting this problem, the resistances of all the connections were checked to see if they are active. This was done using a multimeter. There were active readings on the multimeter, which revealed that all connections were okay and nothing was wrong with the connection module of the relay. A further troubleshooting was done and the relay's parts were dismantled in order to identify the exact problem. It was suspected that the voltage-current module of the relay was the one which had a fault. The module was changed and the problem still persisted. It was after thorough troubleshooting that the fault was pin-pointed. What caused the problem was that a particular connection was duplicated and the relay was seeing this duplication in connection as a fault which was why 'voltage fail' came up. After this particular connection was corrected, the problem was solved and the relay started working as desired.

2) The other problem encountered was that during the Directional Earth Fault (DEF) testing, the DEF LED turned on and did not turn off afterwards as expected. The problem was solved when the MICOM S1 Agile software was accessed and in the design interface, the DEF was 'UNLATCHED', completely deleted and thereafter recreated and 'LATCHED' as a new design. The MCB was also turned off. After taking these troubleshooting steps, the DEF LED finally turned off and the problem was rectified.

3) Another problem encountered was that during the zone testing, there was an earth fault trip so the relay was not seeing Zone 3. This was due to the value of Zone 3 higher than the earth fault value. This made the relay see earth fault before seeing Zone 3. This was why the 'TRIP' LED came on. This was corrected by increasing the earth fault setting to a value higher than the Zone 3 value. After this was done, the problem was rectified.

1.10 PICTURES



Figure 4: The decommissioned faulty SIEMENS 7SA522 relay



Figure 5: The commissioned MICOM P443 relay

1.11 OUTCOME OF PROJECT

From the test results got, all the tests done on the MICOM P443 relay were passed. The inference from this is that the relay is in a good condition and working perfectly. This means that it will provide full protection to the Ayede-Osobgo 330kV transmission line and if at all there is any fault, the relay will respond as expected. The commissioning of the MICOM P443 main 2 distance protection relay on Ayede-Osobgo 330kV transmission line was a huge success.

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