International Journal of Latest Engineering and Management Research (IJLEMR)
ISSN: 2455-4847
www.ijlemr.com || Volume 09 – Issue 03 || March 2024 || PP. 36-44

Evaluation of the Polarized MHO Digital Distance Relay using Polarization Signals

Gustavo Rafael de Souza Reis[1], Willian Marlon Ferreira[1]
[1]*Federal Institute of Minas Gerais, Brazil*

Abstract: This article describes the implementation and analysis of a digital distance relay Polarized MHO with various forms of polarizations. Therefore, their behavior was found for various fault types at certain points in the transmission line: a little ahead of the relay, behind the relay (considering a reverse fault), busbar, and far ahead of the busbar (inside the zone 1 protection). It is also investigated its resistive reach for many fault resistance values, and the change of its operating characteristic for the various fault points on the line, verifying the circle displacement Polarized MHO, dynamically modified under the influence of conditions and fault of polarization voltages used. The simulations were implemented through the MATLAB software, and the behavior was observed in the form of R-X diagrams from data generated by ATP®, using the graphical tool ATP-DRAW®.

Keywords: Digital Relay, Polarized MHO, Dynamic Behavior.

1. INTRODUCTION

Distance relays are used to provide protection against short circuits in transmission lines, and normally have three protection zones, with adjustment being carried out according to the positive sequence impedances of the line. The impedance of the first zone corresponds to 80 to 90% of the total impedance of the protected line, and is adjusted without delay, thus acting instantly. A safety margin of 10 to 20% is necessary due to inaccuracies caused by various sources of error, such as instrument transformers, which can cause the relay to overreach, causing improper operation [1].

The range of the second zone must be adjusted to protect the entire line and the downstream busbar, and its operation is delayed with actuation between 200 and 500 ms. Finally, the third zone is considered as remote backup protection for downstream lines.

In the event of a short circuit in a transmission line, distance relays send signals to circuit breakers at each end in order to disconnect the line. Its behavior can be strongly affected by fault resistance, so that the resistive coverage is small in relation to expected values. Furthermore, and as the main focus of study, faults very close to the busbar where the relay is installed are a problem for protection when using the Conventional MHO (self-polarized), since it has a low range for faults close to the origin. For this reason, this zone unprotected by the relay is considered a dead zone. However, a viable solution for correct relay coverage would be the Polarized MHO characteristic, which becomes very significant to protect short circuits of this nature.

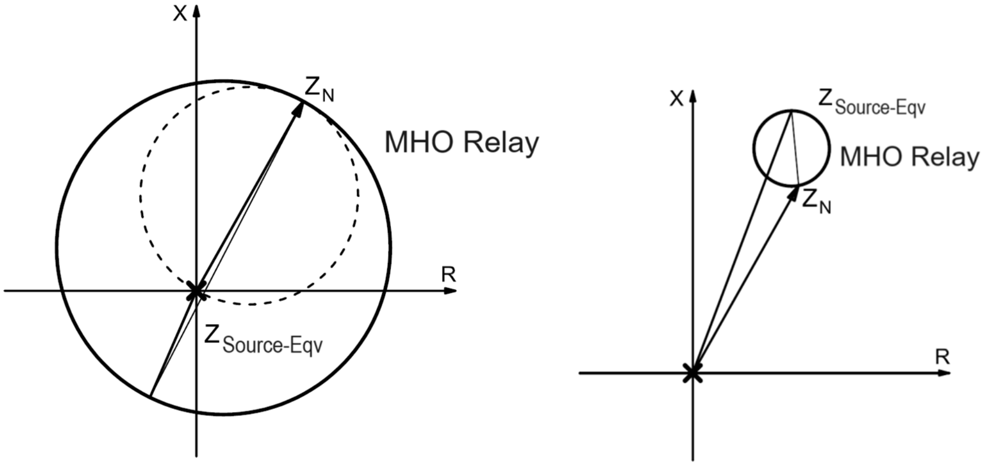
Through simulations, based on the voltage and current values captured in the busbar where the relay is installed, the behavior of a Polarized MHO distance relay during such situations is verified. To this end, the relay input values were obtained using a simulated model in ATP-DRAW® based on previously established parameters. Using the voltage and current signals, the estimated phasors, the impedance seen by the relay and the type of fault that occurred are determined.

2. IMPLEMENTATION OF THE POLARIZED RELAY MHO DIGITAL

The operating characteristic of a Polarized MHO unit is a circle that does not pass through the origin for faults close to the busbar where the relay is located. The displacement of the MHO circle in relation to the origin is a dynamic value and depends on the fault conditions and the polarization voltages used. For faults behind the relay, its characteristic is a circle away from the origin.

As the following figure demonstrates, the area of the relay circle can increase or decrease depending on the point where the fault occurs on the transmission line.

The situation illustrated in Fig. 1(a) occurs when the short circuit is very near the relay busbar or even on the busbar. The expansion of the relay's operating circle can be seen, so that it involves the entire fault point. This characteristic expansion effect is due to the bias introduced into the measurement units. In Fig. 1(b), it can be seen that when the fault is reversed, that is, behind the relay, the operating circle reduces in size and moves away from the fault point.



(a) Fault in front and near the busbar. (b) Fault reverse and near the busbar.

Figure. 1. Displacement operating characteristics resulting from polarization.

To verify the impact of different polarization alternatives, it is worth considering a generic distance relay, using the following signals applied to a cosine phase comparator [2]:

$$\begin{cases} S_1 = I_{Loop} \cdot Z_N - V_{Loop} \\ S_2 = V_{POL} \end{cases} \tag{1}$$

The phase comparator monitors the angular difference between the two different input signals. The operating criterion is given by $-90° < (\angle S_1 - \angle S_2) < 90°$.

If a solid fault occurs on the busbar, or very near to it, where the relay is installed, the reference signal S_2 will not be canceled and the comparator will satisfactorily perform the function for which it was designed. To deal with unbalanced and near-busbar faults ($V_{Loop} \approx 0$), signal S_2 can be provided:
(i) using the combination of phases not affected by the short circuit, known as Single Polarization:

$$S_2 = q \cdot V_Q \tag{2}$$

(ii) using combinations of the phases not affected by the short circuit with the affected phase, known as Dual Polarization:

$$S_2 = f \cdot V_{Loop} + q \cdot V_Q \tag{3}$$

(iii) using combinations of the phases not affected by the short circuit with the phase affected at an instant prior to the fault, known as Dual Polarization with Memory:

$$S_2 = f \cdot V_{Loop} + m \cdot V_M + q \cdot V_Q \tag{4}$$

Where: I_{Loop} is the fault unit current
Z_N is the replica impedance of the transmission line
V_{Loop} is the fault unit voltage
V_{POL} is the bias voltage
V_M is memory voltage
V_Q is the quadrature voltage
f, m, q are positive real values, usually between 0 to 1

The measurement and polarization signals used for the AT and BC fault loops are shown in Tables 1 and 2.

Table 1. Comparator signals for ground loops

Loop of fault	**INPUT SIGNALS**		
	Simple Polarization	**Dual Polarization (Cross)**	**Dual Polarization with Memory**
AT	$\begin{cases} S_1 = (I_A + k_0 \cdot I_{a0}) \cdot Z_N - V_A \\ S_2 = \frac{V_{BC}}{\sqrt{3}} \angle +90^\circ \end{cases}$	$\begin{cases} S_1 = (I_A + k_0 \cdot I_{a0}) \cdot Z_N - V_A \\ S_2 = V_A + q \cdot \frac{V_{BC}}{\sqrt{3}} \angle +90^\circ \end{cases}$	$\begin{cases} S_1 = (I_A + k_0 \cdot I_{a0}) \cdot Z_N - V_A \\ S_2 = m \cdot V_A + q \cdot \frac{V_{BC}}{\sqrt{3}} \angle +90^\circ \end{cases}$

Table 2. Comparator signals for phase loops

Loop of fault	**INPUT SIGNALS**		
	Simple Polarization	**Dual Polarization (Cross)**	**Dual Polarization with Memory**
BC	$\begin{cases} S_1 = I_{BC} \cdot Z_N - V_{BC} \\ S_2 = \sqrt{3} \cdot V_A \angle -90^\circ \end{cases}$	$\begin{cases} S_1 = I_{BC} \cdot Z_N - V_{BC} \\ S_2 = V_{BC} + q \cdot \sqrt{3} \cdot V_A \angle -90^\circ \end{cases}$	$\begin{cases} S_1 = I_{BC} \cdot Z_N - V_{BC} \\ S_2 = m \cdot V_{BC} + q \cdot \sqrt{3} \cdot V_A \angle -90^\circ \end{cases}$

The expression of the zero sequence compensation factor k_0 is given by:

$$k_0 = \frac{Z_{L0} - Z_{L1}}{Z_{L1}} \qquad (5)$$

Where: k_0 is the zero sequence compensation factor
Z_{L0} is the zero sequence replica impedance
Z_{L1} is the positive sequence replica impedance

The expansion of the characteristic operation depends directly on the equivalent impedance of the source seen by the relay, which in turn depends on the chosen bias voltage [3]:

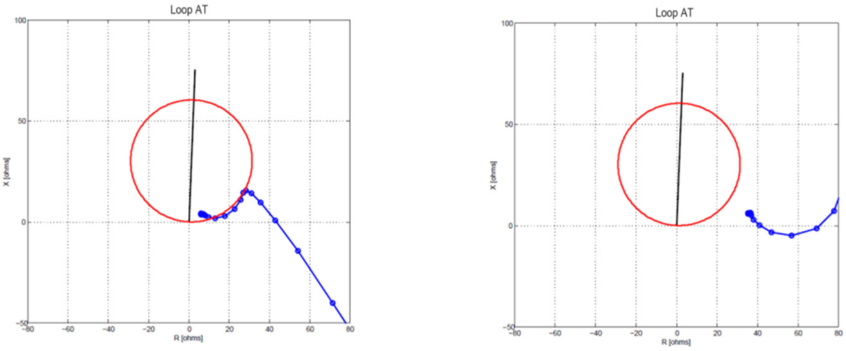
$$Z_{Fonte-Eqv} = \frac{\frac{V_{POL}}{(f + m + p)} - V_{Loop}}{I_{Loop}} \qquad (6)$$

From the previous expression, the dependence of $Z_{Source\text{-}Eqv}$ in relation to the polarization voltages and the short-circuit phase voltage can be seen, so that its value changes for each fault considered. This means that the characteristic obtained for a given $Z_{Source\text{-}Eqv}$ is only valid for the failure point considered [3].

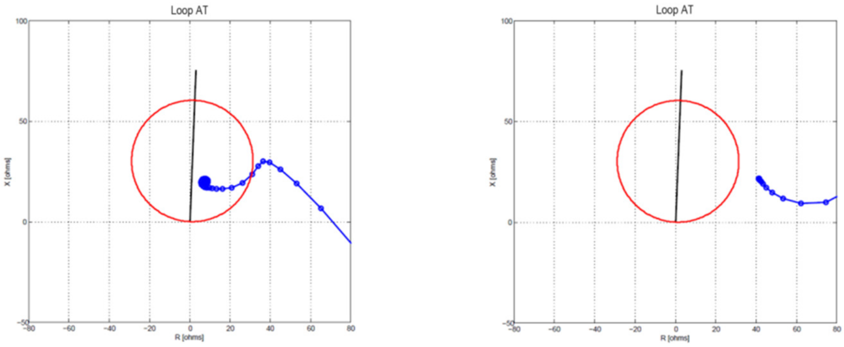
Another important influencing factor to be considered in a distance relay is the fault resistance, which in turn reduces the effective Zone 1 earth leakage range of the MHO type distance relay, such that most faults are detected in Zone 2 time. For this reason, in the presence of fault resistance, its effect must be introduced into the equations and also into the apparent impedance of the system [4].

In cases of faults between phases, the resistances are small, generally less than 0.5 Ω. In faults involving earth, these may have values greater than 10 Ω [5]. In some cases, they can become very high, such as in trees leaning against cables (in the order of 50 Ω to 100 Ω), conductors fallen in highly resistive terrain or even in fires (in the order of 15 to 40 Ω) [6].

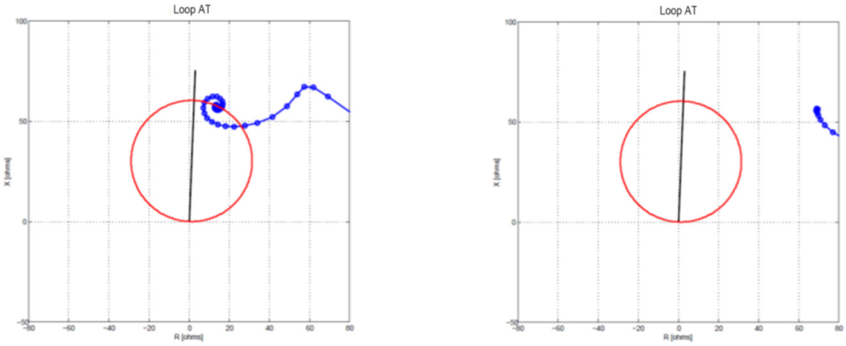
Using a Conventional MHO type relay, and in reference to Fig. 2, an analysis of the influence of fault resistance on the impedance behavior of the model developed in different defect locations with different values for fault resistance is carried out. The increase in resistance results in the relay not acting, as it causes the impedance path to move away from the protected zone.



(a) Single-phase fault at 10 km.



(b) Single-phase fault at 60 km.



(c) Single-phase fault at 180 km.

Figure 2. Conventional MHO Relay for single-phase faults at different points on the LT.
Fault resistance equal to 10 and 60 Ω. 80% LT protection zone.

The analysis of the operation of the Polarized MHO unit is carried out through the fault units that perform their functions for short circuits in the busbar where they are installed, as well as adequately maintain their directional characteristics for faults a little in front and a little behind the busbar. To this end, the following block diagram (Fig. 3) presents the logic of the algorithm used in the implemented digital distance relay:

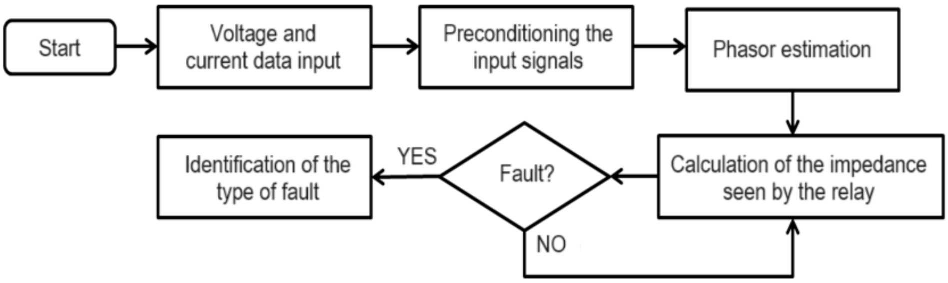


Figure 3. Flow diagram of the implemented algorithm.

To avoid aliasing effects in the phasor estimation process, a classic second-order Butterworth low-pass filter is applied to the input signals. Pre-processing adjusts the input signals to adapt these signals to the operation of the protection filters, performing anti-aliasing filtering and resampling the input data, if necessary [2].The one-cycle Fourier algorithm performs phasor estimation, based on the direct transform of the DFT (Discrete Fourier Transform), extracting the fundamental frequency component of a discrete signal. The estimation of the fundamental frequency component is done by correlating the samples from one cycle of the signal to be filtered with the samples from one cycle of the reference signals, sine and cosine, at the fundamental frequency [7].To do so, it is separated into real and imaginary parts, particularized for the fundamental frequency and with an adjustment in gain, in order to obtain the phasor with a module equal to the peak value of the signal in the time domain [8]:

$$Y_C = \frac{2}{N}\sum_{k=0}^{N-1} x_k \cos\left(\frac{2\pi k}{N}\right) \tag{7a}$$

$$Y_S = \frac{2}{N}\sum_{k=0}^{N-1} x_k\, sen\left(\frac{2\pi k}{N}\right) \tag{7b}$$

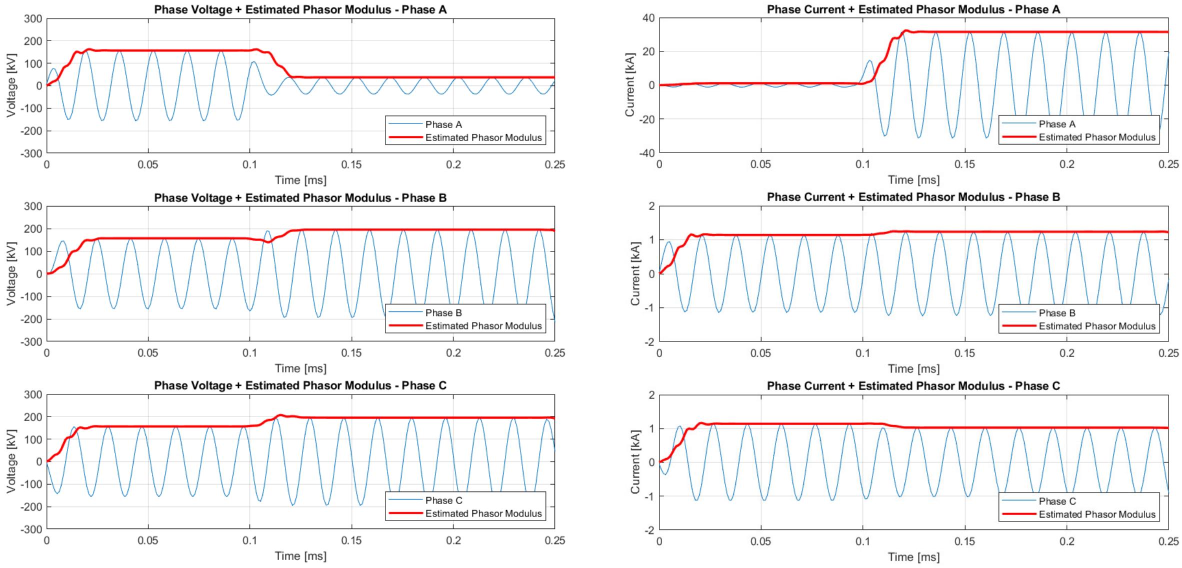
The amplitude and phase of the phasor at the fundamental frequency can be calculated as:

$$Y = \sqrt{Y_C^2 + Y_S^2} \tag{8a}$$

$$\varphi = \tan^{-1}\left(\frac{Y_S}{Y_C}\right) \tag{8b}$$

3. RESULTS

The algorithm is based on the estimation of the voltage and current phasors of the electrical system, as can be seen in Fig. 4. These phasors are adopted for the calculations of the fault loops.

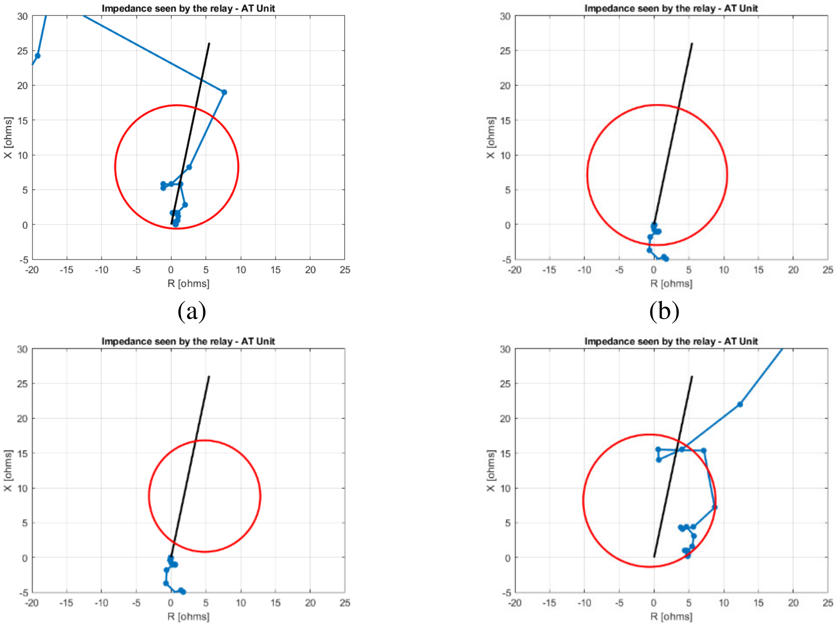


(a) (b)

Figure 4. Phasor estimation: (a) phase voltages, (b) phase currents.

The impedance behavior, as well as the protection zone, is dynamically and graphically analyzed using MATLAB based on the applied polarizations. For the condition of no fault unit actuation, the impedance is located outside the protection zone. The decision for operation is made by comparing, at each instant, this impedance value with the value associated with the specified range of the transmission system to be protected [9].The transmission line under analysis is 51 km, voltage 230 kV, zero sequence resistance equal to

0.5007 ohms/km, zero sequence inductance equal to 4.618146 mH/km, positive sequence resistance equal to 0.1075 ohms/km and positive sequence inductance equal to at 1.357857 mH/km. Fig. 5 shows a single-phase fault using Single Polarization. In this case, the critical situation corresponds to the phase-to-ground fault, where the reduction in the source's equivalent impedance is greater for higher values of k_0 [3].



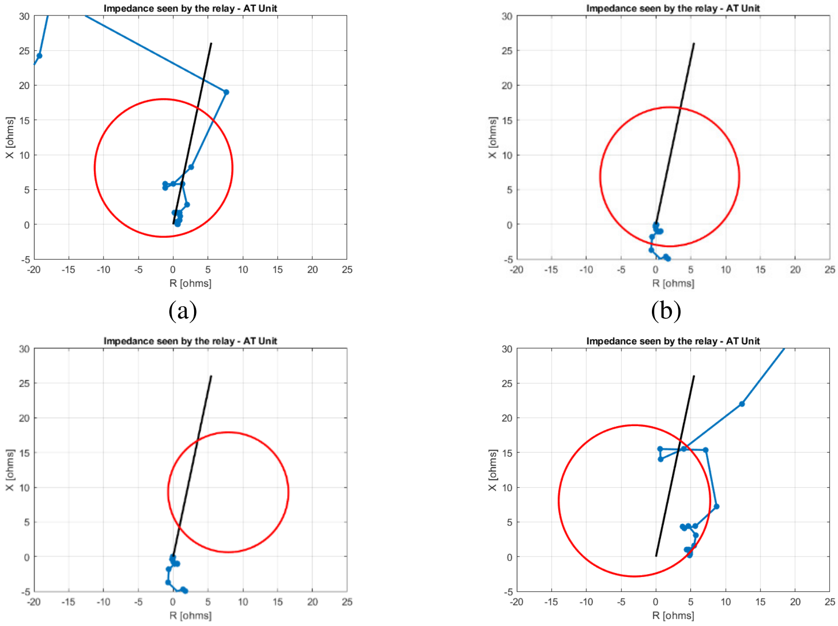
(a) (b)

(c) (d)

Figure 5. MHO Relay Single Polarization – AT fault:
(a) 5 km in front of the busbar, (b) at the busbar, (c) 5 km behind the busbar, (d) 37 km in front.

In the case of Dual Polarization, it is important to verify that the minimum equivalent impedance of the source that leads to a sufficient expansion of the relay characteristic to guarantee fault detection [3].

Fig. 6 demonstrates the relay actuation for fault conditions (a) and (b) near the circle of the actuation zone. In (c) correctly, the protection zone moves away from the defect point. In the condition illustrated in (d), the relay operates due to the weighting applied through the quadrature factor q, thus demonstrating its direct relationship with the expansion of the protection zone.

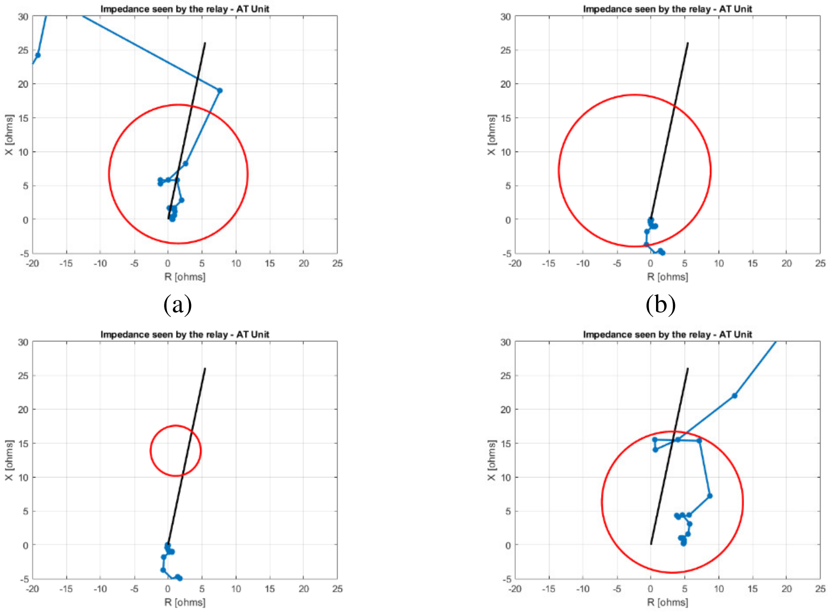


(a) (b)

(c) (d)

Figure 6. Dual Polarization MHO Relay – AT fault:
(a) 5 km in front of the busbar, (b) at the busbar, (c) 5 km behind the busbar, (d) 37 km in front.

Fig. 7 shows the relay polarized based on memory voltages, which are used to ensure that the relay operates correctly when the phase comparator S_2 signal is null (in faults very near the busbar).The main characteristic of memory polarization is the maintenance of the pre-fault voltage during some cycles, ensuring the operation of the distance relay [9].The time required to use this polarization device is the time for the relay to see the fault and make a decision on whether it will act or not. Generally, ¼ cycle is used for decision making. This procedure can be seen in Fig. 7(a) and (b). The implemented algorithm considered a data window of 16 samples per cycle. The relay does not act for the condition illustrated in Fig. 7(c), as it is a reverse fault. In Fig. 7(d) it is due to the weighting of the quadrature factor *q*. Furthermore, the reduction of the protection zone is also affected by the memory factor *m*.

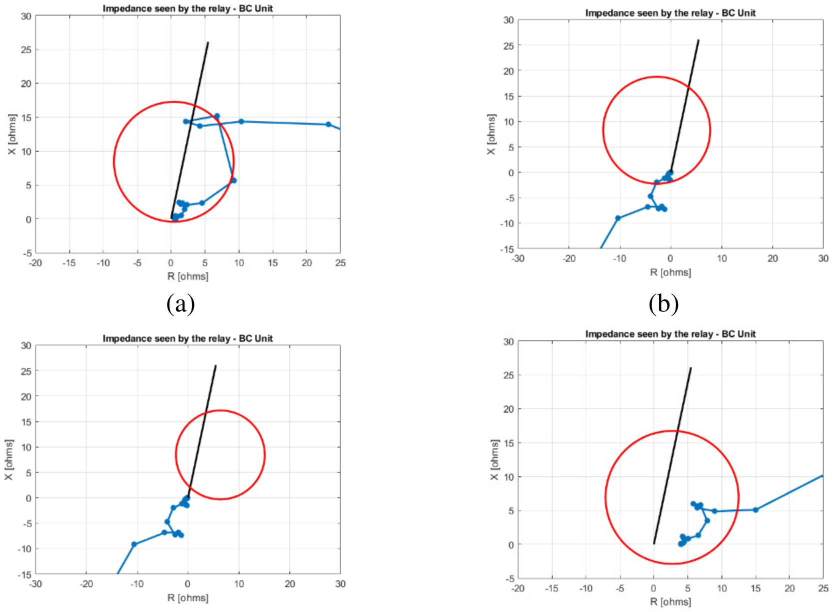


(a) (b)

(c) (d)

Figure 7. Dual Polarization MHO Relay with Memory – AT fault:
(a) 5 km in front of the busbar, (b) at the busbar, (c) 5 km behind the busbar, (d) 37 km in front.

In the case of two-phase faults, the BC phase fault unit sees a BCT fault in the same way as a BC fault. This is to be expected since a BCT fault is formed by the union of BC, BT and CT faults.



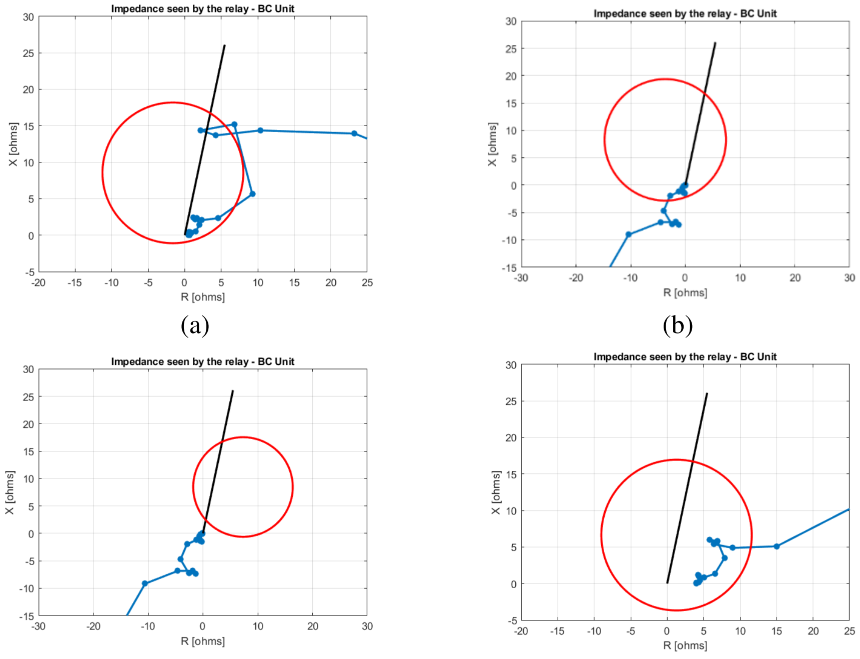
(a) (b)

(c) (d)

Figure 8. MHO Relay Single Polarization – BC fault:
(a) 5 km in front of the busbar, (b) at the busbar, (c) 5 km behind the busbar, (d) 37 km in front.

Single Polarization showed adequate behavior for the defined situations, regardless of the location of the fault, as illustrated in Fig. 8.

Fig. 9(a), (b), (c) and (d) shows good Dual Polarization coverage at the fault point, providing correct actuation of the distance relay. However, care must be taken when determining the quadrature factor, since in certain situations it may cause the relay to underreach.

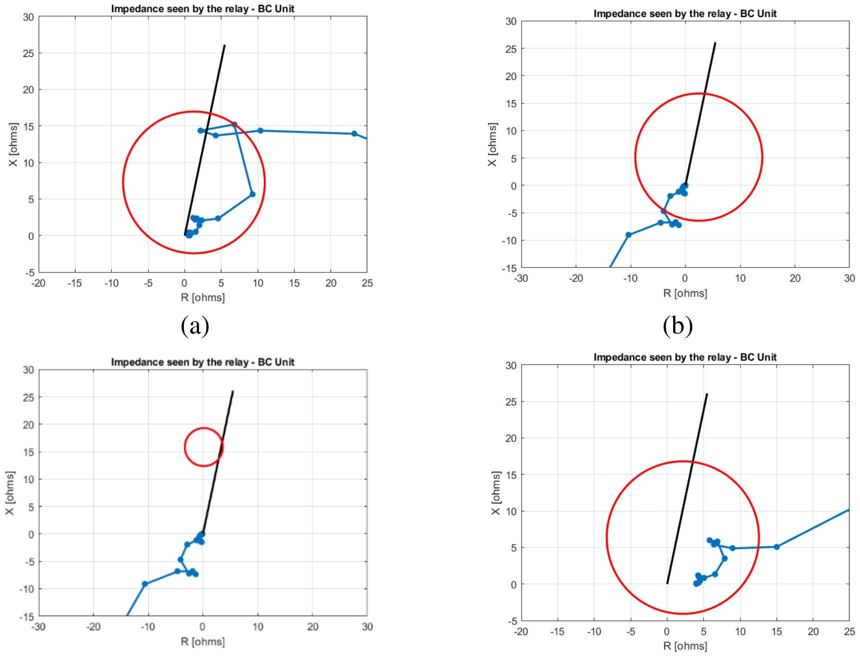


(a) (b)

(c) (d)

Figure 9. Dual Polarization MHO Relay – BC fault:
(a) 5 km in front of the busbar, (b) at the busbar, (c) 5 km behind the busbar, (d) 37 km in front.

The operation of the distance relay, through memory voltages, can be seen in Fig. 10, where protection of the required zone was achieved. An alternative to improving the relay range is to change the values adopted for the *m* and *q* factors.



(a) (b)

(c) (d)

Figure 10. Dual Polarization MHO Relay with Memory – BC fault:
(a) 5 km in front of the busbar, (b) at the busbar, (c) 5 km behind the busbar, (d) 37 km in front.

In the event of a three-phase fault, the voltage level is severely reduced, therefore, the relay loses the polarization signal, in addition to the impossibility of obtaining quadrature voltages. The memory voltage is a form of polarization that guarantees directionality for three-phase shorts near the relay, whether directional or distance. Most relays incorporate cross-polarization and memory voltage to guarantee reference even in three-phase short circuits [9].

4. CONCLUSION

In this article, the behavior of the MHO type distance relay was evaluated for different forms of polarization and its expansion characteristics through the protection zones. The simulated results for a specific electrical system with typical configurations and values were also graphically presented.

Through Single Polarization, the advantages of polarization valid for all ground and phase loops were observed. Furthermore, the expansion of the protection zone is the largest among the other polarizations, thus providing more effective coverage for faults near the busbar or on the busbar itself.

Regarding Dual Polarization, this proved to be an appropriate alternative for zero fault loop voltage, as through combinations of phases not affected by the short circuit, the quadrature voltage is obtained. This type of polarization becomes invalid for three-phase faults since all phase voltages cancel each other out, and likewise, the guarantee of directionality is also nullified.

The memory voltages applied to Dual Memory Polarization are extremely relevant, especially in three-phase faults, as in defects of this nature, all phases are affected by the short circuit, therefore, these memory voltages are used so that the relay correctly performs the protection of the line in question. For digital relays, the memory polarization takes place a few cycles before the moment of fault, thus guaranteeing the relay polarization signal.

Finally, the relays' behavior in the face of reverse faults was confirmed, which correctly showed the distance from the fault point and the relay's non-action for this type of defect.

REFERENCES

[1] Cook, V. Analysis of Distance Protection. Letchworth, Hertfordshire, Inglaterra: Wiley, 1985.
[2] Pereira, C. et al, Uma Plataforma para o Ensino, Pesquisa e Desenvolvimento de Relés Digitais de Proteção, XXI SNPTEE, Florianópolis, Santa Catarina. Anais do XXI SNPTEE, 2011.
[3] Moraes, R. M.; OrdacgiFo, J. M., Sollero, R. B., Effects of polarizing voltages on the choice of distance protections for series compensated transmission lines. Study Committee B5 Colloquium, Calgary, Canada, 2005.
[4] Humpage, W. D.; Kandil, M. S., Discriminative performance of distance protection under fault operating conditions. Proc.IEE, Vol. 115, No. 1, January, 1968.
[5] Blackburn, J. L., Protective Relaying: Principles and Applications. New York: Marcel Dekker, 1987.
[6] Silveira, E. G., Localização Digital de Faltas Em Linhas de Transmissão Com Utilização dos Dados de Um Terminal. Tese de Doutorado, UFMG, 2007.
[7] IEEE Tutorial Course, Computer Relaying, 79 p., 1979.
[8] Phadke, A. G.; Thorp, J. S., Computer Relaying for Power Systems. 2. ed. West Sussex, UK: John Wiley & Sons Inc, 2009.
[9] Siqueira, M. C., Desempenho da proteção de distância sob diferentesformas de polarização. Dissertação de mestrado, UFRJ, 2007.