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The Distance Protection and the Pre-Fault Conditions

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ABSTRACT

In the present time in the Electric System of Power, in occasions you continuous using the distance function (21) as main protection in transmission lines what is not correct since the distance protection is affected by multiple phenomena, say you oscillations of power, effect of the mutual induction among lines, pre-fault conditions that can take to an incorrect operation of the protection, as well as the inability of simultaneous shot in both ends of the line that it protects. In this work the results of the mathematical analysis of a system are presented with lines of 110 kw where the phenomena and difficulties are evidenced that introduce to the distance protection taking alone in bill the negative effect of the flaw resistance and the conditions that existed before the flaw, as well as their possible solutions which are not completely effective.

Keywords: *Distance Protection, Pre-Fault, Short circuit.*

INTRODUCTION

Distance protection is widely used for the protection of transmission networks and should be used as backup protection and not as a primary protection [1], but some engineers do not know the reasons why this backup role should be assigned to it. protection of the lines. The distance protection, protection function (21 ANSI code), is a directional protection by nature, with relative selectivity that has as an organ of measurement an impedance relay, which operates against short circuits in the line it protects. This protection determines the ratio between the voltage and current (impedance) of the line where it is connected, which in conditions of three phase metal failureis no more tan the distance between the connection point and the fault. Distance protections do not always ensure acceptable selectivity for internal short circuits for their first and second steps in most current configurations [2]. For the protection of lines, three steps of the distance protection are used. The first step is adjusted with an impedance of about 80% of the line impedance that is being protected. The second step is adjusted in such a way as to ensure total protection of the line and the third step, it is adjusted to detect faults in the line or the element that is connected down stream. These pre-fault conditions are relatedto [3-4].

- The resistance involved in the failure
- The amount and direction of the transfer of power through the line before the failure or in pre-fault conditions
- The short-circuit powers of the sources at both ends of the line

The distance protection can be realized with several forms or zones of protection, taking into account the length of the line, the supply voltage, the characteristic in the complex plane of the relay, the tendency to occur short circuits with arc resistances and oscillations of system power. Between these forms you can find relays type impedance, relays type MHO, relays with quadrilateral characteristic, and others.

Occasionally pre-fault conditions are not taken into account when making adjustments to the steps of the distance protections, in addition to using it in configurations where it is unreliable. In this paper, it is analyzed using mathematical simulation, how the pre-fault conditions in the operation of the distance relays used in the transmission lines influence negatively when there are electric arcs characterized by their resistance.

MATERIALS AND METHODS

It is important that the behavior of the protections in the Power Electrical Systems (SEP), is extremely reliable, due to the high value of the elements that protect and that the protections constitute the first barrier to achieve the stability of the system against major disturbances. If the protections separate the shorted elements quickly, the system will have more possibilities of achieving stability after thefailure [2-5]. Distance protection is widely used in our country in electric networks with voltages equal to and greater than 110kV. This protection can perform incorrect operations due to numerous factors: effect of intermediate sources, pre-fault conditions, power oscillations, load effect and mutual coupling. The Mho-type distance relay [1-6] is widely used, although currently in most SEPs, the quadrilateral type distance relay isused. The pre-fault conditions occur negatively in the distance protection operation, since the impedance measurement values are affected. In Figure 1, a simplified diagram of a simple circuit line is observed, considering that the short circuit has arc resistance Rf. This scheme will serve as the basis for the analysis of the effect of the pre-fault on the impedance measured by a distance relay.

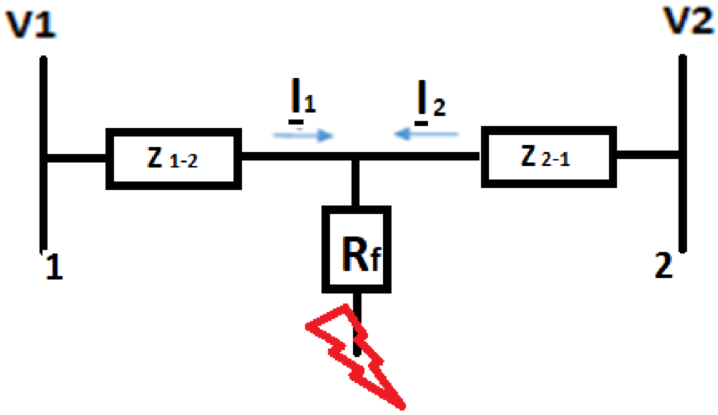

Figure1. *Section of a single line circuit of any transmission network.*

For a distance protection located at the end of the line closest to bus 1 (Fig. 1), for a three-phase fault, it would measure a voltage V1 as a function of equation (1).

$$\underline{V}1=\underline{I}1(\underline{Z}1\text{-}2)+(\underline{I}1+\underline{I}2)Rf=\underline{I}1(\underline{Z}1\text{-}2+Rf)+\underline{I}2\cdot Rf \quad (1)$$

Where:

V1- voltage at the measuring end

I1- current at the measuring end

I2- current at the other far end of the failed line

Rf- resistance involved in the failure

Then total culate the impedance involved in the fault we have equation (2):

$$\underline{Z}1=\frac{\underline{V}1}{\underline{I}1} \quad (2)$$

Simplifying the equation, we obtain equation (3):

$$\underline{Z}1=\underline{Z}1\text{-}2+Rf+\left(\frac{\underline{I}2}{\underline{I}1}\right)Rf \quad (3)$$

As seen in equation (3), the value of the fault impedance measured by the distance relay will not depend only on the impedance involved in the fault line, nor on the resistance involved in the fault (Rf), but also of the currents on both ends of the line.

The impedance measured by the relay depends on the relationship between I2 and I1 whenever there is fault resistance, so it is a real difficulty because in the short circuits there will almost always be Rf, largely contributed by the electric arc. As the measured impedance, when fault resistance exists, it will depend on the intensity of the currents of both those passing through the measurement point, and the currents at the other end of the line and their phase shifts, then the magnitude and angle of these currents will affect the measurement of the impedance. The magnitude of the currents will be subject to the short-circuit capabilities of the sources at both ends of the line and their angles to the state of the transfer before the failure occurs (pre-fault conditions).

Results and Discussion

In the simplified electrical system shown in figure 2, three-phase short circuits will be simulated in the line joining bus 2 and 3 and the values of impedance measurements of the distance relay will be analyzed taking into account the resistance involved in the short circuit and the transfer that existed before the failure.

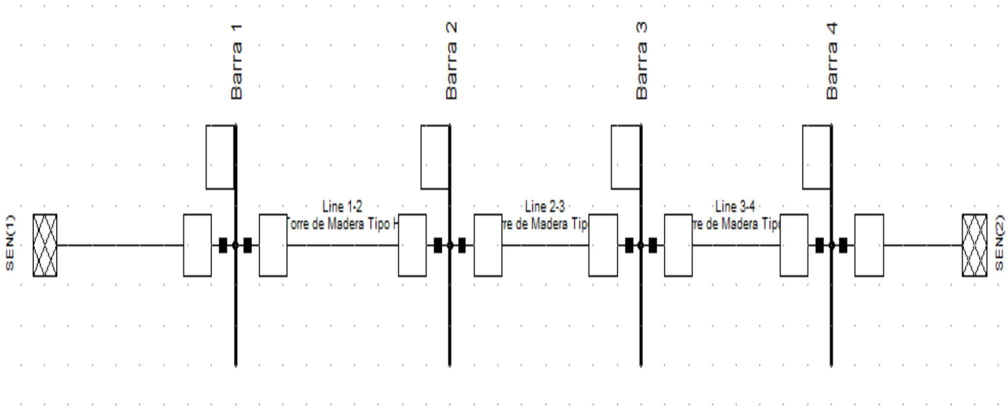

Figure2. *Transmission system with 110 kV tower lines, mounted on the PowerFactory DigSilent 15.1.7 mathematical software*

In this simplified system shown in Figure 2, the lines have the same impedance 0.218Ω + j3.038Ω and have, in turn, the same distance of 10 km. Equivalent systems installed at both ends have 1500 MVA of short circuits. This network operates at 110kV so it is a typical simple network transmission circuit that links two generating areas.

Effect of Fault Resistance

The impedance of a typical transmission line is very inductive. This means that the impedance measured by the relay, in a complex X-R plane, will be on the impedance of the line [2-3]. It would be thought that the effect of the resistance of the arc moves the impedance in the X-R plane, taking it out of the characteristic where the impedance of the line is located as shown in Figure 3. In line 2-3 shown in figure 2, a short circuit at 50% of the line length is simulated and the values of the fault resistance shown in table 1 will be varied. Note that although the fault has not been moved of position the impedance measured by the relay is different for each value of fault resistance.

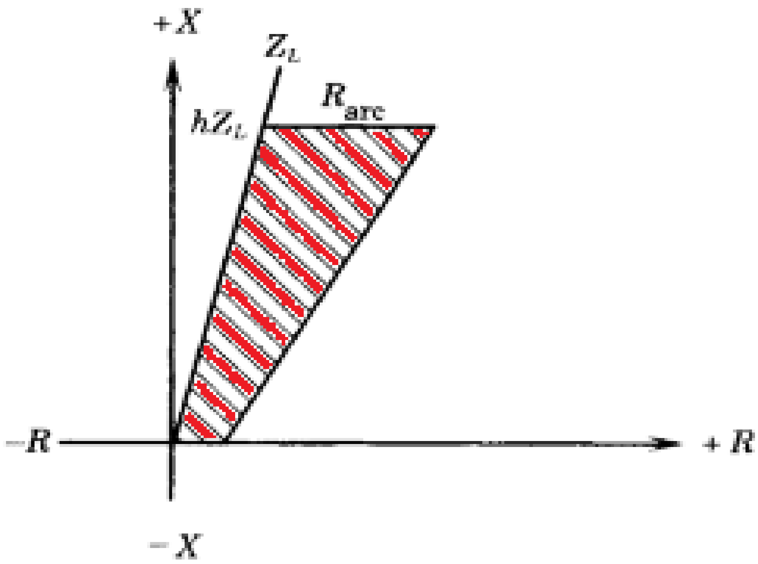

Figure3. *Effect of the fault resistance in the impedance measured by the distance relay [2]*

Table1. *Impedance values measured by the relay for a short circuit at 50% of the line, with different fault resistance values*

Rf (Ω)	Fault impedance (Ω)
0	0,1094 + j1,5231
0.4	0,9000 + j1,5180
0.6	1,3090 + j1,5190
0.8	1,7090 + j1,5190
1	2,1014 + j1,5139
1,2	2,5065 + j1,5170

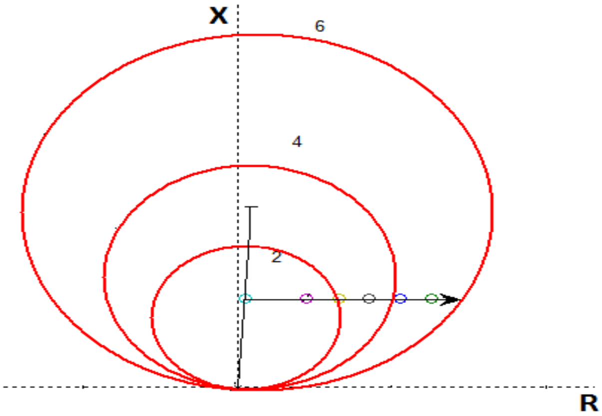

Figure4. *Location of the CC in the operation zones of the distancing relay located in bar 1 with a failure resistance from 0 to 1.2 Ohm in the direction of the bolt.*

Figure 4 shows the operation areas of the analyzed relay, which is the one that is connected to the end closest to bar 2 (Fig. 2), considering that it is an MHO type relay with three operating zones calculated approximately for said line, and considering the failure resistance values shown in Table 1. For an approximate value of 0.8 ohm of fault resistance, the impedance measurement is already operating incorrectly when leaving the first zone of operation if an MHO type distance relay is used, and with the increase of the fault resistance the impedance will be seen by zone 2 and it will even be seen only by zone 3 for higher values of fault resistance.

The problem that introduces the increase that can have the resistance of failure is tried to solve installing a relay of distance with quadrilateral characteristic instead of one Mho [4-7], represented in the figure 5.

With the quadrilateral characteristic the contradiction is reduced existing between the effect of the arc resistance on the non-operation of the relay (which demands a wide characteristic according to the R axis) [2-6].

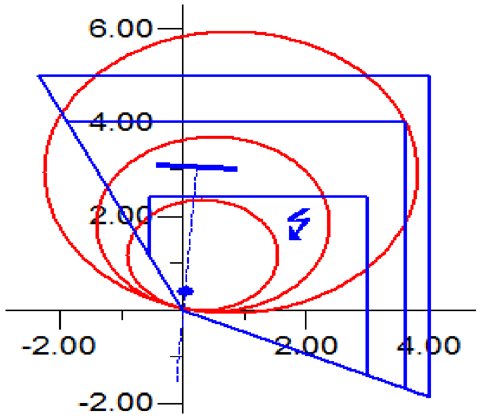

Figure5. *Location of the CC in the operation zones of the Mho and quadrilateral type distance relay with a failure resistance of 0.8 Ohm.*

In Figure 5, it is observed that the fault will remain in the first zone of operation of the quadrilateral relay, which is correct, while in turn the fault is outside the first operating zone of the Mho-type relay, which is not correct. It could be said that the solution of the selectivity problem of the distance relays due to the resistance involved in the fault, is to use quadrilateral relays in the transmission over head lines instead of MHO type relays, but then it will be verified that this solution it is not totally effective.

Effect of the Amount and Direction of Power Transfer along the Line

Consider that the system of Figure 2 has no transfer between the sources and a three-phase fault will be simulated at a point at 50% of the length of line 2-3. Next, it can be seen what happens with the angle of the short-circuit current in the bars to which the fault line is connected. Measurement in Bus 2: -88.653 °

Measurement in Bus 3: -88,033 °

It is observed that the difference between the angles of the measurement of each bar is minimal, less than 1%, so it is not significant. That is, if there is no transfer there is no angular difference between the sources connected to both ends of the line. This is not a normal situation; the normal thing is that there are transfers on the lines.

Now there will be a transfer from System 1 to System 2, which means a shipment of 120 MW, and a 50% failure of line 2-3 will be simulated. The difference between the angles of the currents that enter the line is 43% and this is due to the transfer of active power that existed before the failure that was 120 MW.

Measurement in Bus 2: -57.245 °

Measurement in Bus 3: -99.424 °

The active power transfer that existed before the failure significantly influences the angular difference of the currents from both sources. This angular difference is related to the angle of the emf before the fault occurs and that is why this angle corresponds to the pre-fault conditions. Based on equation (3), it is observed that the value of the fault impedance will not depend only on Rf, but also on the phasor relationship between the currents at both ends of the line. The measured impedance depends on the factor between I2 and I1. As the measured impedance, when there is fault resistance, will depend on the phasors of the currents both those that pass through the measurement point, and the currents at the other end of the line, then the magnitude and angle of these currents will affect the measurement of the impedance. Previously it was evidenced that when the transfer by the line was zero, the angular difference between the currents was smallie I2 / I1 will be practically one if the sources are equal, now when there is a transfer this coefficient will be I2 / I1 will introduce an angular behavior, since there is a difference in these values.

Depending on the direction in which the transfer is found along the lines, for the same short circuit at a point in the middle of line 2-3 for values of resistance of increasing failure, the behavior will be that described by the values in Table 2 and 3.

It is simulated in the same way as the previous experiment a 50% failure of line 2-3, but in this case with power transfer by it sending from System 1 to System 2, 120 MW prior to the failure and then with opposite direction. The values measured by the relay in both experiments can be seen in table 2.

Table2. *Impedance values measured by the relay for different fault resistance values considering the pre-fault conditions with different directions of the transfer.*

Rf (Ω)	Impedance (Ω) for 120 MW From System 1 to System 2	Impedance (Ω) for 120 MW From System 2 to System 1
0.4	0,754 + j1,2173	0,767 + j1,8390
0.6	1,100 + j1,0770	1,100 + j2,0200
0.8	1,398 + j0,9440	1,450 + j2,1900
1	1,665 + j0,8180	1,790 + j2,3800
1.2	1,955 + j0,6990	2,160 + j2,6018

Now we can notice if we compare the results of Table 2, with those obtained in Table 1 that the results of the impedances that the relay would measure for different values of failure resistance are different with and without transfer and depending on the direction that have that transfer.

For 0,8 OHM without transfer before failure the relay would measure 1,709Ω + j1,519Ω, but with 120 MW transfer from system 1 to 2 the same relay with a fault in the same position would measure 1,398Ω + j0,9440Ω and if the transfer is reversed the relay would measure 1,450Ω + j2,190Ω. Since the fault is at the same point at 50% of the line, the relay measures different impedance values each time.

This result shown in tables 1 and 2, means, as it would be assumed from the analysis of equation 3, that the impedance measured by the relay will depend not only if there is fault resistance, nor of its value, but also of the state of transfer that existed before the failure occurred. Note in table 2, that for a resistance of failure of 0.8 ohm the impedance measured by the relay changes not only the resistive component but also the inductive reactive component of the impedance, therefore the point of failure moves no longer in a linear fashion as in the case of figure 4 but transversally. The result of table 2 is taken to the X-R plane shown in figure 6.

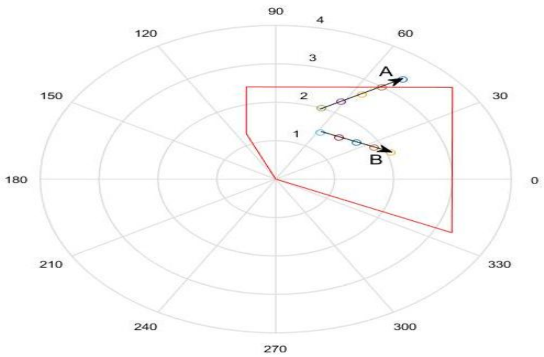

Figure6. *Location in the X-R plane of the fault for arc resistance values, A-with previous transfer from SEN 2 to SEN 1 (Table 2 Values), B-with transfer from System 1 to System 2 (Table 2 Values).*

It is observed that in both cases A and B the characteristic describes a linear behavior but not parallel to the axis of the resistances, with the increase of Rf, which is corroborated what was previously expressed. The angles of the currents involved in the fault have different values and the factor I2 / I1 will introduce a new problem to the distance relay measurements. With this the fault can be left out of the operating zone for smaller values of fault resistance and the reliability would be even lower, for example for a value of Rf = 0.8 Ohm describing the behavior A of Figure (6) and the operation is not reliable due to its proximity to the border of zone 1 of operation, and for higher values it would already be out of zone 1 of operation, this being incorrect [4-7-8].

In figure 6, it was observed that the quadrilateral relay at first suppresses the problems of the fault resistance, but the status of the transfer before the short circuit is still problematic, as well as the DC capacities of the sources, since these introduce an angular behavior, which would cause incorrect shots even faster. To solve this problem, some relays have an option that allows a positive slope to the first operation area (TILT) [4-9] as shown in figure 7.

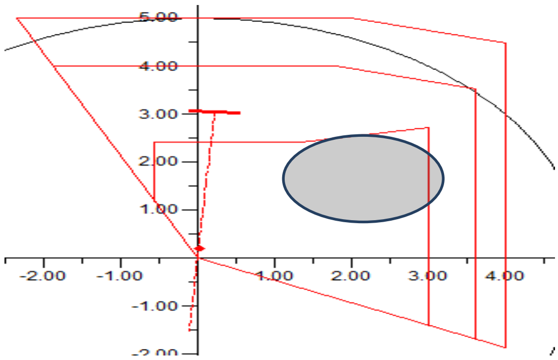

Figure7. *Quadrilateral distance relay with positive slope Tilt in zone 1.*

This option of the TILT eliminates the difficulties of the protection before the conditions described above, essentially the difficulties presented by the behavior a, shown in figure 6, but it will be shown that other problems appear. If a fault is simulated in line 3-4 at 50% of its length (Fig. 8) and the operation zones of both relays are observed, a new problem will be noticed.

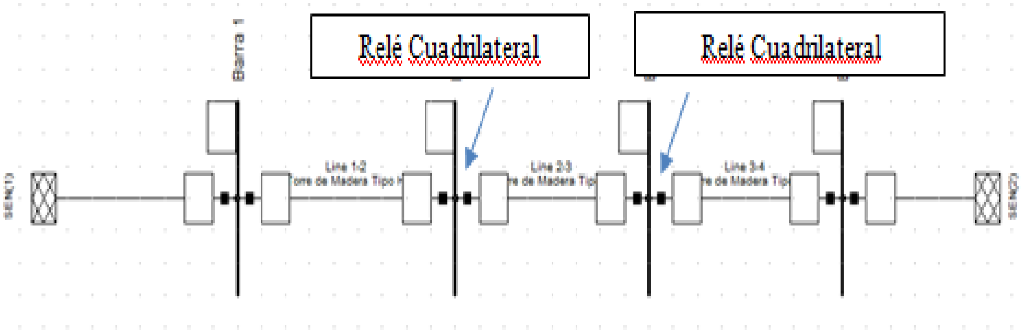

Figure8. *Descripción de la falla en la línea aguas abajo.*

When the Quadrilateral operation zones of two versions of the lines that are a continuation of the other person are shown in the same graph, it is observed as shown in Figure 9. The signals of a positive note (TILT) are observed. Zone 1 of the operation before the behaviors analyzed above. It can also be observed that an area is introduced in zone 1 of the relay of the next line where the operation can be performed and a single fault.

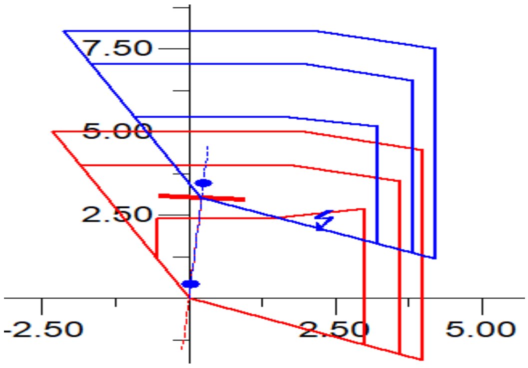

Figure9. *Operating zones of the relays shown in figure 8.*

That is, the solution of the TILT can solve the problema that by the transfer before the fault zone 1 does not see a fault, but the nan other problem of selectivity would appear because two protections Zone 1 could see the same fault and both would disconnect both lines.

Effect of the Short-Circuit Powers of the Sources at Both Ends of the Line

The effect of the short-circuit powers is essentially reflected in the fault current module with out practically affecting the fault angle. An increase in the short-circuit power translates into a greater contribution to the fault current and vice versa. When the short-circuit powers are equal, the currents for each end of the fault line will be the same and the error will be only twice the fault resistance. In the power electrical systems in the transmission lines, it is difficult to fore see the short-circuit levels at each end, since these lines carry the weight of the generation that varies according to the needs of the system. When the short-circuit powers at each end of the line are different, the errors that introduce the fault resistance and the transfer through the lines before the fault can be higher or lower depending on the magnitude of the currents at each end. If, at the end where the measurement is made, the greatest contribution of the fault current occurs (I1>I2), the error that introduces the difference of I2 and I1 in the measurement will be lower tan when the inputs are equal (see equation 3 and Table 3), this being a favorable condition. But when the current supply that passes through the measurement point is less tan the contribution that comes from the other end (I2>I1) the error will be greater (see Table 3). A greater error in the measurements means that for smaller values of fault resistance and less transfer across the lines, the consequences of these errors will be worse for the correct operation of the distance relay.

Table3. *Impedance values measured by the relay for different scenarios (Currents in cases that are not equal, the highest current is twice the value of the lower one).*

$I_1=I_2$		$I_1>I_2$	$I_2>I_1$
Rf (Ω)	**Fault impedance(Ω)**	**Fault impedance(Ω)**	**Fault impedance (Ω)**
0	0,1094 + j1,5231	0,1095+j1,520	0,1091+1,519
0.4	0,9000 + j1,5180	0,682+j1,517	1,431+j1,529
0.6	1,3090 + j1,5190	0,96+j1,516	2,09+j1,534
0.8	1,7090 + j1,5190	1,255+j1,515	2,753+j1,540
1	2,1014 + j1,5139	1,542+j1,514	3,414+j1,545
1,2	2,5065 + j1,5170	1,829+j1,513	4,07+j1,550

Conclusions and Recommendations

When all the results of the models are analyzed, the following is concluded:

- During faults in the aerial transmission networks, whether to ground or phase to phase, if fault impedance exists, the distance relay will measure the location or distance of the fault in an incorrect manner.
- The possible solutions to the problems introduced by the fault resistance and the

increase or decrease of transfer, replacing a relay type MHO with a relay with quadrilateral characteristic are not effective at 100%.

- The measurement errors of the distance relay increase with the increase in the short-circuit power of the source at the other end of the line.
- These errors in the measurement can cause unnecessary delays in the operation of the relay that can be dangerous for the stability of the system.

REFERENCES

[1] Blackburn, J. Lewis. Protective Relaying Theory and Applications. Third Editions. Taylor & Francis Group. LLC. 2014. p. 638.ISBN 13: 9780824791520. [Consultado octubre de 2017]. Disponible en: https://www. amazon.es/ Protective-Relaying-Principles-Applications-Engineering-ebook/dp/B009 AI90SQ

[2] Anderson, P.M. Power System Protection. Power Math Associates, Ten Editions. New York, IEEE Press and McGraw-Hill, 2010. p.1305. ISBN 0-7803-3427-2. [Consultado octubre de 2017]. Disponibleen: https://www. lehmanns.de/shop/technik/2559355-9780780334274-power-system-protection

[3] Mason, C. R., "The Art and Science of Protective Relaying", John Wiley & Sons, New York, 2005. p.410. ISBN 13: 9780471 575528. [Consultado octubre de 2017]. Disponibleen: https://www.iberlibro.com/servlet/BookDetailsPL?bi=30070324863

[4] Technical Manual MiCOM P44x Numerical Distance Protection, Edited June 2013, V D3.0. Disponibleen: https://www.schneider-electric. Com.co/es/download/document/P44x_ EN_M_Ka7__E0__M/.

[5] Kundur, "Power Systems Stability and Control". Dr. Neal, Editor-in-Chief. First edition. California, McGraw Hill ,1994. p.1176. ISBN 0-07-035958-Xy. [Consultado octubre de 2017]. Disponibleen: https://www.amazon.com/ System-Stability-Control-Prabha-Kundur/dp/ 007035958X

[6] Stevenson, W. D. "Elements of power systems analysis". 4th edition. Auckland: McGraw-Hill, 1982, p.436, ISBN-13: 978-0070612785. [Consultado octubre de 2017]. Disponible en:https://www.researchgate.Net/publication/44529335_Elements_of_power_systems_analysis_William_ D_Stevenson

[7] Ramón M. Mujal Rosas. Protección de Sistemas Eléctricos De Potencia. Primera edición, Edición de la Universidad Politécnica de Catalunya. septiembre de 2002. p.197, ISBN: 84-8301-607. [Consultado octubre de 2017]. Disponible en: https://www.iberlibro .com/9788476539729/Protecci%C3% B3n-sistemas-el%C3%A9ctricos-potencia-UPC Postgrau-847653972X/ plp

[8] CIGRE Study committee 34 "Application guide on protection of complex transmission network configuration". In: CIGRE SC34-WG04. Publication E50400-U0048-U211-A3-7600 May 2014. [Consultado octubre de 2017]. Disponible en: https://es.scribd.com /document /49775083/Cigre-WG-34

[9] Z.Y.Xu, S. J. Jiang, Q.X.Yang, T.S.Bi. "Ground distance relaying algorithm for high resistance fault", A IET Gen. Transm. Distrib .vol.4, no.1, pp. 27-35, (2010), doi: 10.1049 /iet-gtd.2009.0353.

[10] Elmore, W.A. Protective Relaying. Theory and Applications. Second Editions. Marcell Dekker Inc. 2000. p.426. ISBN: 0-8247-0972-1 [Consultado octubre de 2017].

[11] Disponibleen:https://books.google.com.cu/books?hl=es&lr=&id=1Jqhpd-rhoUC&oi=fnd&pg=PR3&dq=Protective+Relaying.+Theory+and+Applications.+Second+Editions&ots=mcQjrsAswi&sig=UX09CjtFS3PxcHA7wKBpEF3-X0w&redir_esc=y#v=onepage&q=Protective%20Relaying. %20Theory%20and%20 Applications. %20 Second%20 Editions&f= false

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