Article
Journal of Systematic Innovation
June 2023 Vol.7 No.20 27-34

Study of the overcurrent protection coordination for radial and ring fed system

Estudio de la coordinación de protección de sobre corriente para sistema radial y en anillo

SHIH-Meng Yen†, LEZAMA-ZÁRRAGA, Francisco Román, SALAZAR-UITZ - Ricardo Rubén* and SANCHEZ-QUINTAL, Ricardo Jesús

Universidad Autónoma De Campeche, Campus V, Predio s/n por Av. Humberto Lanz Cardenas y Unidad Habitacional Ecologica Ambiental, Col. Ex-Hacienda Kala, CP 24085, San Francisco de Campeche, Cam., México.

ID 1st Author: *Meng Yen, Shih* / **ORC ID:** 0000-0001-7475-6458, **CVU CONAHCYT ID:** 408617

ID 1st Co-author: *Francisco Román, Lezama-Zárraga* / **ORC ID:** 0000-0003-3397-7881, **Researcher ID Thomson:** U-1229-2018, **CVU CONAHCYT ID:** 205493

ID 2nd Co-author: *Ricardo Rubén, Salazar-Uitz* / **ORC ID:** 0000-0003-2307-737X, **CVU CONAHCYT ID:** 416277

ID 3rd Co-author: *Ricardo Jesús, Sánchez-Quintal* / **ORC ID:** 0009-0003-8437-931X, **CVU CONAHCYT ID:** 786068

DOI: 10.35429/JSI.2023.20.7.27.34 Received March 14, 2023; Accepted June 29, 2023

Abstract

The distribution systems are normally protected by inverse time overcurrent protection devices. This is due to the natural behavior to tolerate temporal overloading conditions on the distribution lines and its inexpensive cost. Therefore, both radial and ring fed distribution systems are protected using this protection principle. However, the manual time coordination procedure can be tedious and confusing for the new undergraduate protection students. For this reason, this article presents the overcurrent and directional overcurrent protection coordination study considering two parameter settings: time dial and pickup current.

Directional Overcurrent Relay Coordination, Manual Coordination, Radial and Ring Fed System

Resumen

Los sistemas de distribución se protegen normalmente con los dispositivos de protección de sobre corriente de tiempo inverso. Este debido a la naturaleza de poder ofrecer operaciones de sobrecarga temporal en las líneas y por su propiedad económica. Por lo tanto, en sistemas tanto radiales y anillados de distribución, se emplea este principio de protección. Sin embargo, el procedimiento manual de la coordinación por tiempo puede ser un poco tedioso y confuso para los nuevos estudiantes de pregrado de la asignatura de protecciones. Por tal motivo, en este articulo se presenta el estudio de coordinación de protección de sobre corriente y de sobre corriente direccional considerando los dos parámetros de ajustes: la palanca de tiempo dial y la corriente de arranque.

Coordinación Manual, Coordinación de Relevador de Sobre corriente Direccional, Sistema Radial, Sistema en Anillo

Citation: SHIH-Meng Yen, LEZAMA-ZÁRRAGA, Francisco Román, SALAZAR-UITZ - Ricardo Rubén and SANCHEZ-QUINTAL, Ricardo Jesús. Study of the overcurrent protection coordination for radial and ring fed system. Journal of Systematic Innovation. 2023. 7-20: 27-34

* Correspondence to Author (e-mail: rrsalaza@uacam.mx)
† Researcher contributing as first author.

Introduction

To protect electrical power systems, protective devices are employed to perform electrical fault release functions (Uzair, M., Li, L., Eskandari, M., *et al*). Electrical faults can come from nature or human erroneous operations. Then the protective devices have the task to isolate the faulted zone from the electrical network to avoid possible accidents and loss of expensive primary equipment (Blackburn & Domin 2006, section 1.1).

The Over Current Relay (OCR) is mostly employed in distribution systems due to its virtue of tolerating temporary overloads. The OCR is used for single source radial systems and the Directional over Current Relay (DOCR) is used for ring systems with one or more sources. Fault currents are used as an indicator of the location of electrical faults that may flow into or out of the primary or backup protection zone.

Directional over Current Relays (DOCRs) are employed in ring systems to achieve fault direction discrimination and thus adjust the relays (Gers & Holmes 2011, p.125).

Both OCRs and DOCRs need to be adjusted so that they can act as primary protection in their own zone and backup protection in remote zone for distribution lines (Gers & Holmes 2011, p.5-6).

The coordination of RCOs and DOCRs aim to minimize primary operation time (Rojnić, M., Prenc, R., Topić, D. *et al*) and simultaneously offering delayed backup operation time (Blackburn & Domin 2006, section 1.1).

Justification

Overhead lines are the most prone to electrical failures due to natural phenomena due to long distances exposed in the open. Therefore, in order to offer a good electrical supply service while minimizing energy discontinuity and avoiding premature burnout of expensive primary equipment, utilities choose to design and implement protective devices to protect equipment and personnel.

Coordination of RCOs on a radial distribution line can be done by current. However, it is preferred to use time coordination, which can give better results in terms of selectivity of the protections. This is of utmost importance and necessary in ring or meshed networks. Often as the electrical network grows and equipped with higher number of OCRs or DOCRs, the complexity of and time required to execute well the coordination study increases (Gers & Holmes 2011, p.96-97).

Therefore, in this paper aspires to present the study of the coordination problem of radial line OCR and ring line DOCR protections coordination problem for the new undergraduate students of the subject of protections.

Objective

To develop in a manual way and showing clearly the concepts, considerations and steps of OCR and DOCR coordination in radial and ring system.

Mathematical Modeling of the Inverse Time Overcurrent Relay

Overcurrent relays can operate according to IEEE or IEC standard. In the case of this work, it is based on the IEEE C37.112-1996 standard presented in equation 1. Both OCR and DOCR have inverse time characteristic curves. This means that they can be operated in shorter time (fast response) when the magnitude of the fault current is large; and operated in longer time (slow response) when the magnitude of the fault current is small, thus tolerating temporary overloads, or magnetizing current.

$$t = \left[\frac{A}{\left(\frac{I_{sc^{3\emptyset}_{max}}}{I_p} \right)^n - 1} + B \right] * dial \qquad (1)$$

Where t is the operating time of the relay, $I_{sc^{3\emptyset}_{max}}$ is the maximum three‒phase fault current, I_p is the pickup current of the relay normally set between 1.4 to 2 times the maximum load current, $dial$ is the time lever setting or family of curves, y A, B, n is the IEEE standard constants.

ISSN 2523-6784

The IEEE constants defining the conventional inverse time characteristic curves of the overcurrent protection are presented in Table 1. Moderately inverse (MI), very inverse (VI) and extremely inverse (EI). The IEEE curves consider the effect of magnetic saturation of the core relays.

Standard	Curve	A	B	n
IEEE	MI	0.0515	0.114	0.02
	VI	19.61	0.491	2
	EI	28.2	0.1267	2

Table 1 IEEE Standard Constants
Source: IEEE Standard Inverse-Time Characteristic Equations for Overcurrent Relays, IEEE std C37.112-1996

Inverse Time Over Current Protection

The inverse time over current protection (OCR, 51) uses the input signals from the current transformers (CTs) and compares them to the preset value of the inrush current.

If the input current signal exceeds the preset value, then the OCR detects an overcurrent scenario and sends a trip signal to the circuit breaker which will open its contacts to de-energize the protected line. The OCR has no directionality, and is therefore used only in single source radial systems. The OCR operating logic is presented in Figure 1.

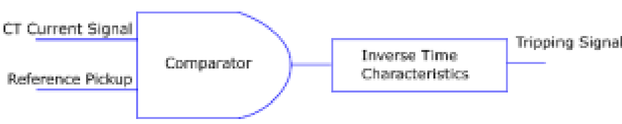

Figure 1 OCR tripping logic
Source: Own Elaboration

Time-reversed directional overcurrent protection (DOCR, 67) are designed to measure the current operating conditions in an electrical circuit and send trip signals to the circuit breakers if an electrical fault is detected. Unlike the OCR, DOCRs have directionality.

Two major measuring instruments are required to perform the DOCR function: current transformer (CT) and potential transformer (PT). Each DOCR is biased with TP voltage signals to be used as reference signal. And when the fault occurs, the phase relationship between voltage and current are analyzed to determine the direction of the fault (Blackburn & Domin 2006).

The DOCR first discriminates whether the fault is located in front of or behind the relay. If the fault is located behind the relay, then no trip signal is sent. However, if the fault is located in front of the relay, a comparison of the fault magnitude and the reference current is made to decide whether or not to send a trip signal to the breaker. The DOCR operating logic is presented in Figure 2.

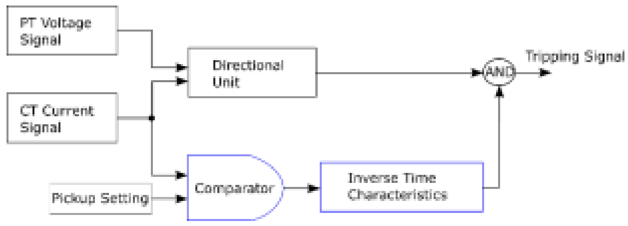

Figure 2 DOCR tripping logic
Source: Own Elaboration

DOCRs only trip when fault events are "in front of" and do not trip for fault events when they are "behind". They are used in radial systems with more than one source, in ringed and meshed systems to discriminate the fault location.

When the current flow is not in the direction of the relay direction, it will not be measured and, therefore, will not trip the relay. In Figure 3, it illustrates that relays A and D detect the load currents of the sources while relays B and C do not detect them because they are in the opposite direction of the current. If a fault occurs on the line located between buses 2 and 3; relays A, C and D will detect the fault and relay B will not detect it because the fault is behind relay B. Similarly, if a fault occurs on the line between buses 1 and 2; relays A, B and D will detect the fault and relay C will not detect the fault because the fault is behind relay C.

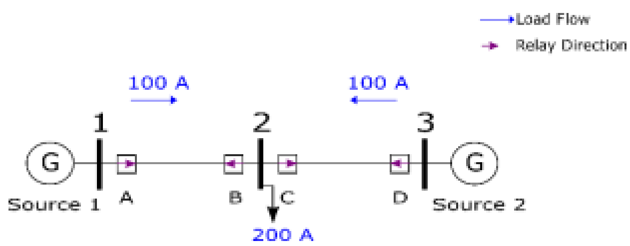

Figure 3 Direction of the DOCRs
Source: Own Elaboration

ISSN 2523-6784

Reverse Time Overcurrent Protection Manual Coordination Procedure

The manual procedure for the coordination of OCRs and DOCRs is presented below:

1. Choose one of the IEEE curves, moderately inverse (MI), very inverse (VI) and extremely inverse (EI). Thus to obtain the constants A, B and n. Other standards or from other manufacturers can also be used.

2. Propose the dial time lever for the first over current relay presented in equation 2.

$$dial_{(primary)} = 0.5 \qquad (2)$$

It is recommended to use the smallest dial parameter for the first relay in order to minimize the operating time of the relays to be coordinated.

3. Calculate the primary operating time as presented in equation 3.

$$t_{primary} = \left[\frac{A}{\left(\frac{I_{sc3\emptyset max\ primary}}{I_{pickup_{primary}}}\right)^{n} - 1} + B\right] * dial_{primary} \qquad (3)$$

4. Calculate the backup relay operating time as presented in Equation 4.

$$t_{backup} = t_{primary} + CTI \qquad (4)$$

The backup relay operating time is calculated by adding a coordination time interval (CTI). This is a delay control of each coordination pair. So, when a primary relay fails to release a fault, the backup can come into operation after the preset CTI time. The CTI is the sum of breaker operating time, electromechanical relay disc overtravel and a safety factor. It can be 0.2 to 0.5 seconds, but is often taken as 0.3 seconds.

5. Calculate the backup relay dial parameter.

$$dial_{backup} = \frac{t_{backup}}{\left[\frac{A}{\left(\frac{I_{sc3\emptyset max\ backup}}{I_{pickup_{backup}}}\right)^{n} - 1} + B\right]} \qquad (5)$$

Repeat steps 3, 4 and 5 continuously until coordination between the different overcurrent relay coordination pairs is established. While steps 1 and 2 are only executed once at the beginning of the coordination process. The coordination of a pair of inverse time relays is illustrated in Figure 4. Based on Figure 3, relay A will provide backup to relay C. This is illustrated with the inverse time characteristic curve in Figure 4.

Where there must be a CTI time between the coordination pair to avoid simultaneous tripping.

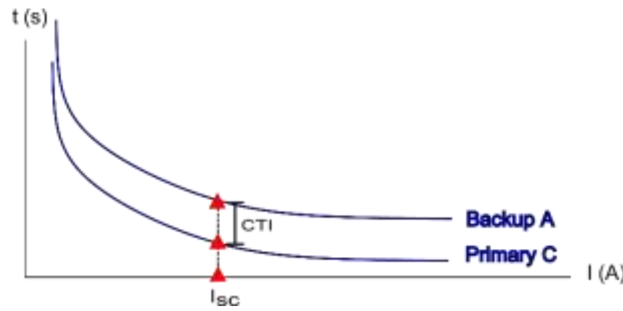

Figure 4 Coordination pair: primary relay and backup
Source: Own Elaboration

It is recommended to use the same curve or in other words the same degree of inversion to avoid possible crossing of curves that leads to loss of coordination. Although using the same curve does not guarantee coordination. When all the OCRs or DOCRs in a system are not coordinated, the process must be started again with a different initial condition (dial time lever).

Study of Manual Coordination of OCRs in a Radio System

Figure 5 shows a single source radial system where OCRs are used. Next, the development of the OCR coordination calculations is presented considering a safety factor k of 1.5 and a CTI of 0.3 seconds.

The steady state load current data as well as the fault currents are presented in Figure 5 and Table 2 and 3.

ISSN 2523-6784

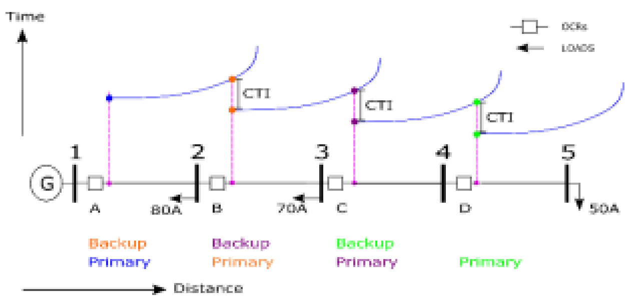

Figure 5 Topology of a radial system with OCRs
Source: Own Elaboration.

Bus	Isc 3ph Primary
1	2000
2	1500
3	1000
4	500

Table 2 Short currents in each bus.
Source: Own Elaboration.

Relay	Isc P	Isc B	Iload	Ipickup
A	2000	1500	80+70+50	300
B	1500	1000	70+50	180
C	1000	500	50	75
D	500	--	50	75

Table 3 Load and short-circuit current data for each relay
Source: Own Elaboration

The coordination study is carried out:

1. Choose the very inverse IEEE curve where has the constants A, B, n are 19.61, 0.491 and 2 respectively according to Table 1.

2. Propose dial for the first relay $dial_{(primary)} = 0.5$.

3. Calculate primary operating time of relay D

$$t_{R_D} = \left[\frac{A}{\left(\frac{I_{sc3\emptyset_{R_D}}}{I_{pickup_{R_D}}}\right)^n - 1} + B\right] * dial_{R_D} = \left[\frac{19.61}{\left(\frac{500}{75}\right)^2 - 1} + 0.491\right] * 0.5 = 0.4712$$

4. Calculate operating time for backup relay C

$$t_{R_C} = t_{R_D} + CTI = 0.4712 + 0.3 = 0.7712$$

5. Calculate dial for backup relay C.

$$dial_{R_C} = \frac{t_{R_C}}{\left[\frac{A}{\left(\frac{I_{sc3\emptyset_{R_C}}}{I_{pickup_{R_C}}}\right)^n - 1} + B\right]} = \frac{0.7712}{\left[\frac{19.61}{\left(\frac{500}{75}\right)^2 - 1} + 0.491\right]} = 0.8273$$

6. Calculate the primary operating time for relay C

$$t_{R_C} = \left[\frac{A}{\left(\frac{I_{sc3\emptyset_{R_C}}}{I_{pickup_{R_C}}}\right)^n - 1} + B\right] * dial_{R_C} = \left[\frac{19.61}{\left(\frac{1000}{75}\right)^2 - 1} + 0.491\right] * 0.8273 = 0.4980$$

7. Calculate the operating time of backup relay B

$$t_{R_B} = t_{R_C} + CTI = 0.4980 + 0.3 = 0.7980$$

8. Calculate the dial of the backup relay B

$$dial_{R_B} = \frac{t_{R_B}}{\left[\frac{A}{\left(\frac{I_{sc3\emptyset_{R_B}}}{I_{pickup_{R_B}}}\right)^n - 1} + B\right]} = \frac{0.7980}{\left[\frac{19.61}{\left(\frac{1000}{180}\right)^2 - 1} + 0.491\right]} = 0.6953$$

9. Calculate the primary operating time of relay B

$$t_{R_B} = \left[\frac{A}{\left(\frac{I_{sc3\emptyset_{R_B}}}{I_{pickup_{R_B}}}\right)^n - 1} + B\right] * dial_{R_B} = \left[\frac{19.61}{\left(\frac{1500}{180}\right)^2 - 1} + 0.491\right] * 0.6953 = 0.5406$$

10. Calculate the backup operating time of relay A

$$t_{R_A} = t_{R_B} + CTI = 0.5406 + 0.3 = 0.8406$$

11. Calculate the dial of the backup relay A

$$dial_{R_A} = \frac{t_{R_A}}{\left[\frac{A}{\left(\frac{I_{sc3\emptyset_{R_A}}}{I_{pickup_{R_A}}}\right)^n - 1} + B\right]} = \frac{0.8406}{\left[\frac{19.61}{\left(\frac{1500}{300}\right)^2 - 1} + 0.491\right]} = 0.6426$$

ISSN 2523-6784

12. Calculate the primary operating time of relay A.

$$t_{R_A} = \left[\frac{A}{\left(\frac{I_{sc3\emptyset_{R_A}}}{I_{pickup_{R_A}}} \right)^n - 1} + B \right] * dial_{R_A} =$$

$$\left[\frac{19.61}{\left(\frac{2000}{300} \right)^2 - 1} + 0.491 \right] * 0.6426 = 0.6056$$

Relay	tp	tb	dial	Ipickup
A	0.6056	0.8406	0.6426	300
B	0.5406	0.7980	0.6953	180
C	0.4980	0.7712	0.8273	75
D	0.4712	--	0.5000	75

Table 4 Results of primary and backup operation times and the parameters of dial and pickup settings of each relay
Source: Own Elaboration.

DOCR Manual Coordination Study in a Ring System

Figure 6 shows a two-source ring system where DOCRs are used. Next, the development of the DOCR coordination calculations is presented considering a safety factor k of 1.5 and a CTI of 0.3 seconds.

The steady state load current data as well as the fault currents are presented in Figure 6 and Table 5.

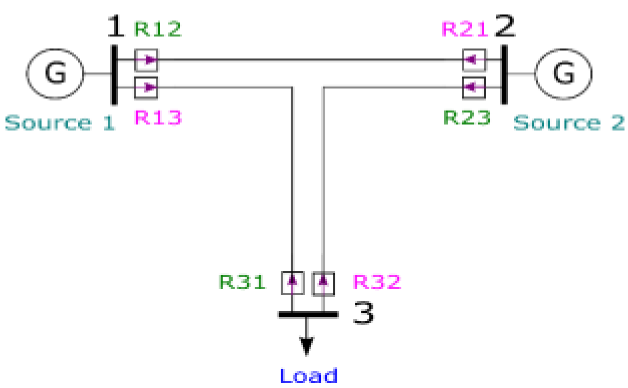

Figure 6 Topology of a ring system with DOCRs
Source: Own Elaboration

Relay	Isc P	Isc B	Iload	Ipickup
1 2	8051	4020	589	883
2 1	8072	4088	589	883
2 3	8515	5716	255	382
3 2	7957	3582	255	382
1 3	8508	7723	826	1239
3 1	5934	3664	826	1239

Table 5 Load and short-circuit current data for each relay.
Source: Own elaboration.

The coordination study is carried out in a clockwise direction:

1. Choose the very inverse IEEE curve where has the constants A, B, n are 19.61, 0.491 and 2 respectively according to Table 1

2. Propose dial for the first relay$dial_{R31} = 0.5$.

3. Calculate primary operating time of the relayR_{31}

$$t_{R_{31}} = \left[\frac{A}{\left(\frac{I_{sc3\emptyset_{R_{31}}}}{I_{pickup_{R_{31}}}} \right)^n - 1} + B \right] * dial_{R_{31}} =$$

$$\left[\frac{19.61}{\left(\frac{5934}{1239} \right)^2 - 1} + 0.491 \right] * 0.5 = 0.6924$$

4. Calculate operation time for backup relay R_{23}

$$t_{R_{23}} = t_{R_{31}} + CTI = 0.6924 + 0.3 = 0.9924$$

5. Calculate the dial for the backup relay R_{23}

$$dial_{R_{23}} = \frac{t_{R_{23}}}{\left[\frac{A}{\left(\frac{I_{sc3\emptyset_{R_{23}}}}{I_{pickup_{R_{23}}}} \right)^n - 1} + B \right]} =$$

$$\frac{0.9924}{\left[\frac{19.61}{\left(\frac{5716}{382} \right)^2 - 1} + 0.491 \right]} = 1.714$$

6. Calculate primary relay operation timeR_{23}

ISSN 2523-6784

$$t_{R_{23}} = \left[\frac{A}{\left(\frac{I_{sc3\emptyset_{R_{23}}}}{I_{pickup_{R_{23}}}}\right)^{n} - 1} + B\right] * dial_{R_{23}} =$$

$$\left[\frac{19.61}{\left(\frac{8515}{382}\right)^{2} - 1} + 0.491\right] * 1.714 = 0.9094$$

7. Calculate operating time for backup relayR_{12}

$$t_{R_{12}} = t_{R_{23}} + CTI = 0.9094 + 0.3 = 1.2094$$

8. Calculate dial for backup relay R_{12}

$$dial_{R_{12}} = \frac{t_{R_{12}}}{\left[\frac{A}{\left(\frac{I_{sc3\emptyset_{R_{12}}}}{I_{pickup_{R_{12}}}}\right)^{n} - 1} + B\right]} =$$

$$\frac{1.2094}{\left[\frac{19.61}{\left(\frac{4020}{883}\right)^{2} - 1} + 0.491\right]} = 0.8143$$

9. Calculate the primary relay operating time R_{12}

$$t_{R_{12}} = \left[\frac{A}{\left(\frac{I_{sc3\emptyset_{R_{12}}}}{I_{pickup_{R_{12}}}}\right)^{n} - 1} + B\right] * dial_{R_{12}} =$$

$$\left[\frac{19.61}{\left(\frac{8051}{883}\right)^{2} - 1} + 0.491\right] * 0.8143 = 0.5942$$

10. Calculate the backup relay operation time R_{31}

$$t_{R_{31}} = \left[\frac{A}{\left(\frac{I_{sc3\emptyset_{R_{31}}}}{I_{pickup_{R_{31}}}}\right)^{n} - 1} + B\right] * dial_{R_{31}} =$$

$$\left[\frac{19.61}{\left(\frac{3664}{1239}\right)^{2} - 1} + 0.491\right] * 0.5 = 1.5115$$

We proceed to perform the coordination study in a counterclockwise direction:

1. Choose the very inverse IEEE curve where has the constants A, B, n are 19.61, 0.491 and 2 respectively according to Table 1

2. Propose dial for the first relay$dial_{R21} =$ 0.8094.

3. Calculate primary operating time of the relay R_{21}

$$t_{R_{21}} = \left[\frac{A}{\left(\frac{I_{sc3\emptyset_{R_{21}}}}{I_{pickup_{R_{21}}}}\right)^{n} - 1} + B\right] * dial_{R_{21}} =$$

$$\left[\frac{19.61}{\left(\frac{8072}{883}\right)^{2} - 1} + 0.491\right] * 0.8094 = 0.5896$$

4. Calculate operation time for backup relay R_{32}

$$t_{R_{32}} = t_{R_{21}} + CTI = 0.5896 + 0.3 = 0.8896$$

5. Calculate the dial for the backup relay R_{32}

$$dial_{R_{32}} = \frac{t_{R_{32}}}{\left[\frac{A}{\left(\frac{I_{sc3\emptyset_{R_{32}}}}{I_{pickup_{R_{32}}}}\right)^{n} - 1} + B\right]} =$$

$$\frac{0.8896}{\left[\frac{19.61}{\left(\frac{3582}{382}\right)^{2} - 1} + 0.491\right]} = 1.241$$

6. Calculate primary relay operation timeR_{32}

$$t_{R_{32}} = \left[\frac{A}{\left(\frac{I_{sc3\emptyset_{R_{32}}}}{I_{pickup_{R_{32}}}}\right)^{n} - 1} + B\right] * dial_{R_{32}} =$$

$$\left[\frac{19.61}{\left(\frac{7957}{382}\right)^{2} - 1} + 0.491\right] * 1.241 = 0.6655$$

7. Calculate primary relay operation time R_{13}

$$t_{R_{13}} = t_{R_{32}} + CTI = 0.6655 + 0.3 = 0.9655$$

8. Calculate dial for backup relay R_{13}

$$dial_{R_{13}} = \frac{t_{R_{13}}}{\left[\frac{A}{\left(\frac{I_{sc3\emptyset_{R_{13}}}}{I_{pickup_{R_{13}}}}\right)^{n} - 1} + B\right]} =$$

$$\frac{0.9655}{\left[\frac{19.61}{\left(\frac{7723}{1239}\right)^{2} - 1} + 0.491\right]} = 0.9568$$

ISSN 2523-6784

9. Calculate the primary relay operating time R_{13}

$$t_{R_{13}} = \left[\frac{A}{\left(\frac{I_{sc3\emptyset_{R_{13}}}}{I_{pickup_{R_{13}}}} \right)^n - 1} + B \right] * dial_{R_{13}} =$$

$$\left[\frac{19.61}{\left(\frac{8508}{1239} \right)^2 - 1} + 0.491 \right] * 0.9568 = 0.8763$$

10. Calculate backup relay operating time R_{21}

$$t_{R_{21}} = \left[\frac{A}{\left(\frac{I_{sc3\emptyset_{R_{21}}}}{I_{pickup_{R_{21}}}} \right)^n - 1} + B \right] * dial_{R_{21}} =$$

$$\left[\frac{19.61}{\left(\frac{4088}{883} \right)^2 - 1} + 0.491 \right] * 0.8094 = 1.1742$$

Realy	tp	tb	dial
1 2	0.5942	1.2094	0.8143
2 1	0.5896	1.1742	0.8094
2 3	0.9094	0.9924	1.7140
3 2	0.6655	0.8896	1.2410
1 3	0.8763	0.9655	0.9568
3 1	0.6924	1.5115	0.5000

Table 6 Results of primary and backup operating times and the parameters of each relay's dial settings.
Source: Own Elaboration.

Coordination Couples	tp	tb	CTI
[1 2] [2 3]	0.9094	1.2094	0.3000
[2 1] [1 3]	0.8763	1.1742	0.3000
[2 3] [3 1]	0.6924	0.9924	0.3000
[3 2] [2 1]	0.5896	0.8896	0.3000
[1 3] [3 2]	0.6655	0.9655	0.3000
[3 1] [1 2]	0.5942	1.5115	0.9173

Table 7 Results of primary and backup operation times and CTIs of each coordination pair
Source: Own Elaboration.

Acknowledgements

The authors are grateful for the support and effort of the Universidad Autónoma de Campeche for its researchers and students to disseminate the research topics in which they are immersed.

Conclusions

The study of overcurrent protection coordination is of great importance in radial or ring overhead line systems. Without proper setting or coordination of OCRs and/or DOCRs, it can lead to possible damage to electrical substation personnel and primary equipment in a power failure scenario. Therefore, the step-by-step study and methodology of OCRs and DOCRs coordination is presented in this paper.

In a radial system, the coordination process is started from the farthest relay from the power source, proposing a minimum dial setting. And eventually the last OCR that is close to the source is coordinated.

In a ring system, a starting point is chosen and coordinates the system. But if the DOCRs are not coordinated by the time you close the ring, then you will have to choose another starting point and repeat the coordination again. Therefore, repeat until the ring system is coordinated.

References

Blackburn J. L. & Domin T. J. (2006). *Protective relaying, principles and applications*. (3rd edition). CRC Press Taylor & Francis Group.

Gers J. M. & Holmes E. J. (2011). *Protection of Electricity Distribution Networks*. (3rd edition). IET. Book DOI: 10.1049/PBPO065E

IEEE Standard Inverse-Time Characteristic Equations for Overcurrent Relays, IEEE std C37.112-1996. https://standards.ieee.org/ieee/C37.112/2646/

Rojnić, M., Prenc, R., Topić, D., & Saulig, N. (2023). *Overcurrent relay optimization in a radial distribution network considering different fault locations*. Electrical Engineering, 105(2), 1093-1109. https://doi.org/10.1007/s00202-022-01718-x

Uzair, M., Li, L., Eskandari, M., Hossain, J., & Zhu, J. G. (2023). *Challenges, advances and future trends in AC microgrid protection: With a focus on intelligent learning methods*. Renewable and Sustainable Energy Reviews, 178, 113228. https://doi.org/10.1016/j.rser.2023.113228