Published by JScE as Proceedings of 4th International Conference on Role of Energy on Sustainable Social Development (RESSD-2025), 29-30 May, 2025, Kathmandu, Nepal

PROTECTION COORDINATION STUDY AND ANALYSIS OF SECTION OF INTEGRATED NEPAL POWER SYSTEM

Jitesh Kumar Yadav[1*], Shreeshuva Maharjan[1], Samundra Gurung[1]

[1] Department of Electrical and Electronics Engineering, Kathmandu University

Abstract

The increasing complexity and dynamism of modern power systems, driven by growing load demands, renewable energy integration, and network expansions has necessitated robust protection coordination strategies to ensure system reliability and operational security. This paper presents a comprehensive protection coordination study and analysis of a particular section of the Integrated Nepal Power System (INPS). The study highlights the interaction between OCRs-to-OCRs and distance relays-to-OCRs under various fault conditions. The system was modeled in DIgSILENT Power Factory, and the analysis was done accordingly. A model of a 66 kV, 65 km transmission network with two generators (17.55 MW), external grid and 30.7 MW load was simulated. Symmetrical and unsymmetrical fault scenarios were created and tested to assess primary and backup relays operations. The findings showed that the present relay settings are capable of isolating the faults under various fault conditions, ensuring the coordination time interval (CTI).

Keywords: Coordination time intervals, Distance relays, Integrated Nepal power system, Protection coordination, Over-current relays

1. Introduction

The Integrated Nepal Power System (INPS) serves as the national electricity grid of Nepal, which interconnects the large number of generation plants, transmission networks, and distribution systems across the country. With the increasing demand for reliable and stable electricity supply, INPS has undergone significant expansion in terms of capacity addition, network reinforcement, and system interconnection. This has made the system to be more complex and dynamic, thus requiring for the robust protection system which can ensure the safety, reliability, and stability of operations (Jungang et al., 2015).

Protection coordination is a key aspect of this infrastructure so that the power system can detect and isolate faults immediately without causing widespread outages or damage in equipment (M. Singh, 2017). The main aim of the protection scheme is to restrict the spreading of fault towards the healthy section of the power system (Hong et al., 2021). A good protection coordination scheme is the one, which isolates the faulty section in order to avoid the unnecessary interruption of the power system (Rahim et al., 2019). This coordination helps prevent cascading failures, improves system reliability, and reduces the impact of faults on the grid (Dashti et al., 2018).

Protection coordination involves the systematic arrangement and operation of protective devices. For example, if the fault occurs in the system, the protective equipment closer to the fault operates first, while upstream devices act as backup if the primary device fails (P. Singh et al., 2024). The key principles of protection coordination include sensitivity, selectivity, speed, and reliability (Altuve et al., 2016). Achieving effective protection coordination requires careful setting of protection devices such as, over-current relays, distance relays, and differential relays (Khond and Dhomane, 2019). Magnitude of fault current, time-current characteristics (TCC) of protective devices, grading margin between primary and backup devices, and network topology are some of the critical factors which influence the coordination of the system (Babu et al., 2020). Moreover, for the system like INPS, where a wide range of voltage levels and diverse generation profiles exist, protection system must balance responsiveness with stability in order to avoid the unnecessary tripping under transient disturbances or minor faults.

*Corresponding author: Jitesh Kumar Yadav
Department of Electrical and Electronics Engineering, KU
Email: jitesh9223@student.ku.edu.np
https://doi.org/10.3126/jsce.v12i2.91414

The coordination of protective equipment is one of the critical issue in the power system engineering. Over the years, a significant amount of research has been conducted to optimize protection schemes and minimize unnecessary operation times of protective devices (Kumar and Rana, 2024). In (Jungang et al., 2015), the author had addressed the critical issue of coordination between the relay protection system and the stability control system in regional power grids, which are typically independent and can lead to power blackouts due to their lack of integration. The authors of paper (M. Singh, 2017) provides a comprehensive review of the challenges and methodologies related to protection coordination on distribution systems, particularly in the context of increasing penetration of distributed energy resources (DERs). In paper (Dashti et al., 2018), the author presents an assessment and improvement of protection coordination for the electrical network of the South Pars Gas Complex's third refinery in connection with the power grid. The methodology involving optimization of the coordination between distance relays and directional over-current relays (DOCRs) in transmission network has been explored in (M. Singh et al., 2018). The paper (Naresh and Sudarshana, 2020) implements over-current relay coordination on an IEEE 9-bus system using MI Power software, where the relay coordination is performed by setting Time Multiplier Setting (TMS) and Plug Multiplier Setting (PMS) for proper primary and backup relay operation.

This study aims to provide the thorough analysis of present operating condition of the relays of INPS. Based on the findings, several recommendations are proposed to address existing protection gaps, thereby enhancing the network's adaptability and resilience in the face of future challenges, including higher renewable energy penetration, network expansions, and evolving load patterns.

The paper is organized as follows: Section 2 discusses about the theoretical background. The Section 3 shows the detailed system description. The methodology used for the analysis is discussed in Section 4. The results and discussion are presented in Section 5, and the paper is concluded in Section 6.

2. Theoretical Background

The different types of relays are used in power transmission line to ensure system protection, fault detection, and coordination. The types of relays include:

2.1. Distance Relays

Distance relays or impedance relays or mho relays are a type of protective relay used in power systems to detect faults on transmission lines based on the impedance between relay location and fault. Typically, this type of relay uses multiple zones of protection, is as shown in Figure 1. Zone-1 covers 80% of the total line length and operates without any planned time delay. The reach of zone-2 is 100% of the protective line length, plus at least 20% of the shortest adjacent line and with the time delay of 20-30 cycles for coordination. Likewise, zone-3 covers 100% of the protective line length, plus 100% of adjacent line, plus 20% of the third line and with time delay of 75-90 cycles, (Bhuvanesh et al., 2010). The operating reach, Z of a mho relay is given by Equation (1), (Bhuvanesh et al., 2010).

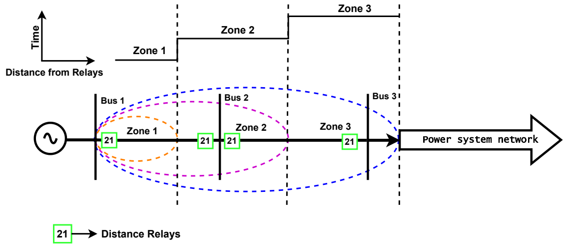

Figure 1. Characteristics of distance protection

$$Z = \frac{Z_{line}}{cos(\theta - \tau)} \quad (1)$$

where,
θ = phase angle of line,
τ = Maximum Torque Angle (MTA), and
Z_{line} = Impedance of considered line.

2.2. Over-current Relays (OCRs)

OCRs are utilized as both main and backup protection for lines up to 66 kV, whereas for 132 kV and 220 kV lines, distance relays serve as the primary protection, with OCRs acting as backup (M. Singh et al., 2018). This relay will issue a trip signal to isolate the faulty part from rest of the system once the system current magnitude exceeds the predefined value of current. Based on the relay's operating time, OCR can be classified as (Bhuvanesh et al., 2010).

- Instantaneous over-current relay
- Time delayed over-current relay
- Inverse-time over-current relay
- Directional over-current relay

The characteristic curves of different types of inverse-time over-current relays is shown in Figure 2. The general equation, which covers the standard inverse-type characteristics is given by Equation (2), (Bhuvanesh et al., 2010).

$$t_{oc} = \frac{\beta * TMS}{(PSM)^{\alpha} - 1} \quad (2)$$

where,
t_{oc} = Operating time of over-current relay,

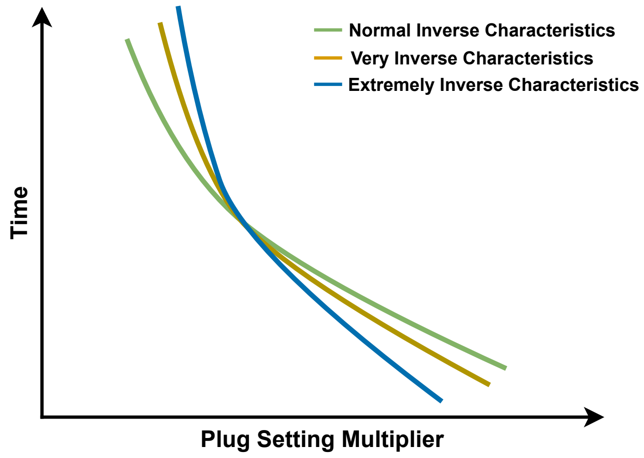

Figure 2. Characteristic curves of inverse-time over-current relays

TMS = Time Multiplier Setting
PSM = Plug Setting Multiplier, and
α and β are relay parameters as IEC standards.

3. System Description

The system used for the study consists of two generators, making the total generation of 17.55 MW. The total load of the system is 30.7 MW. The other generation of INPS has been considered as external grid. A total of 65 km of 66 kV transmission line length is considered for the study. The SLD of system in Figure 3, where the Indrawati-Panchkhal and Sunkoshi-Panchkhal lines provide dual infeed to Panchkhal Grid SS and Panchkhal-Banepa transmission line facilitates power transfer to the wider grid, termed as external grid. The relay placements across the different power stations is tabulated in Table 1, where D and R are referred to as distance and over-current relays respectively. The mho distance relay uses three zone settings, where first and second stages settings of directional over current relays (OCRs) are used for study of protection coordination study in the system model.

Table 1. Placement of relay at different power stations

Power Stations	Relay Placements
INDRAWATI PS	(D4, R4)
SUNKOSHI PS	(D6, R6)
PANCHKHAL S/S	(D3, R3), (D5, R5), (D2, R2)
BANEPA S/S	(D1, R1)

4. Methodology

The methodology of the study is shown in Figure 4. System data such as, transformer, generators, transmission lines, loads and relays parameters are collected from the utility of Nepal. The model was created and simulated in the DIgSILENT PowerFactory software. The missing data of distance relays were manually calculated using Equation (1) based on load flow analysis and short circuit analysis of the system. After the placement of relays, as according to the Table 1, the analysis was done based on the standard CTI.

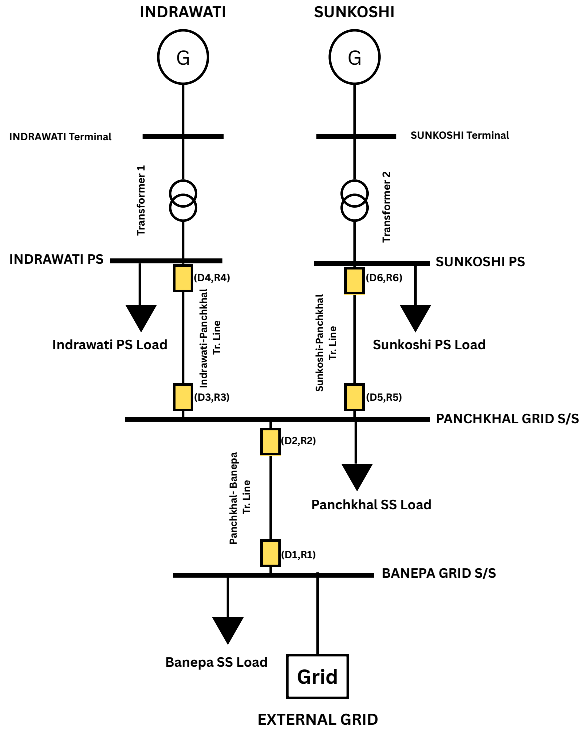

Figure 3. System considered for the study

On protected transmission line, distance relays are the main protective elements for line protection and over-current (OCRs) relays act as backup relays to the distance relays. To avoid the nuisance tripping of relays, backup (OCRs) are set in such a way that they should operate with a time delay after operation of main distance relays. This intentional time delay is known as coordination time interval (CTI).

4.1. OCR-to-OCR Coordination

The backup OCRs must be operated only after the operation of main OCRs with maintaining the CTIs between them, as given by Equation (3).

$$T_{B,OCR} - T_{P,OCR} \geq CTI \tag{3}$$

where, $T_{B,OCR}$ & $T_{P,OCR}$ are operating time of backup and main over-current relays (OCRs). Equation 3 also represent the operating time constraints between main and backup OCRs. In transmission lines, CTI between two OCR is selected between 0.2 s to 0.4 s in order

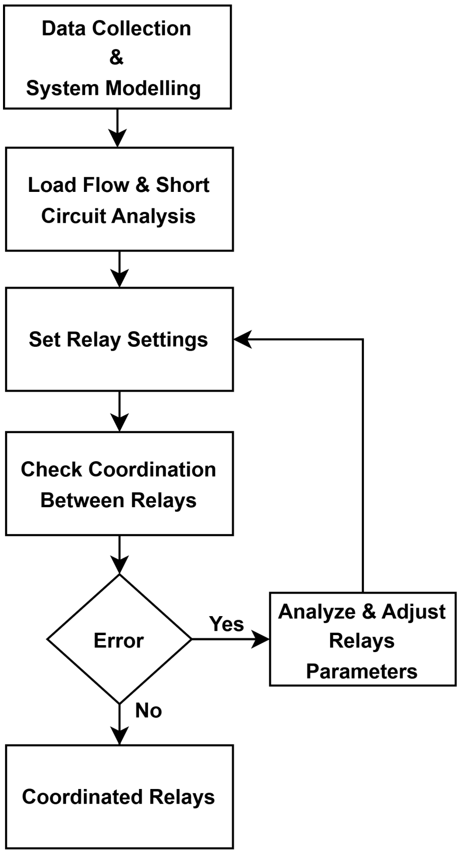

Figure 4. Flow diagram for the study

to ensure the reliable backup protection, (*IEEE Standard for Inverse-Time Characteristics Equations for Overcurrent Relays*, 2018).

4.2. Distance-to-Backup OCRs Coordination

The backup OCRs must be operated after operation of zone-2 of distance relays with maintaining the CTIs between them, as given by Equation (4).

$$T_{B,OCR} - T_{Z2,Distance} \geq CTI \tag{4}$$

where, $T_{B,OCR}$ & $T_{Z2,Distance}$ are the operating time of backup OCRs and zone-2 of distance relays respectively. Equation (4), also represent the operating time constraints between zone-2 of distance relays and backup OCRs. The standard CTI between zone-2 protection of distance relays and backup OCRs must be in between 0.25 s to 0.4 s, (Anderson et al., 2021).

5. Results and Discussion

5.1. OCR-to-OCR Coordination

Figure 5 shows the operating time of primary and backup OCRs, along with CTI for different fault locations. When a unsymmetrical fault, single line-to-ground (LG) occurs on the Panchkhal-Banepa transmission line, the relay pairs (R1, R2) acts as primary protection relay and (R4, R6) operates as backup protection relays with the operating time of (0.100 s, 0.100 s) & (0.450 s, 0.418 s) respectively, ensuring the coordination time interval of (0.350 s, 0.318 s) for reliable back up protections.

Similarly, when fault occurs on the Indrawati-Panchkhal transmission line & Sunkoshi-Panchkhal line, the relay pairs (R3, R4) & (R5, R6) acts as primary protection with operating time of (0.09 s, 0.09 s) & (0.08 s, 0.08 s) respectively. In this case, R1 acts as backup protection relay with operating time of (0.371 s, 0.379 s) respectively, ensuring the coordination time interval of (0.281 s, 0.299 s).

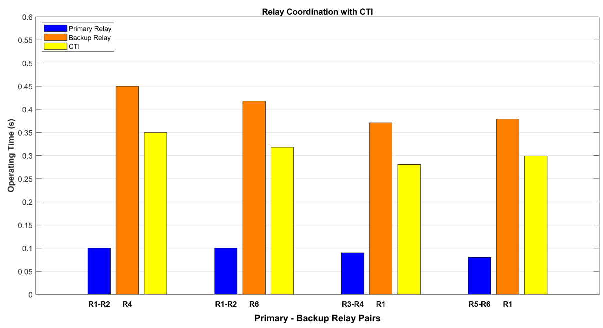

Figure 5. Operation of earth relays (LG)

Figure 6 shows the operating time of primary and backup OCRs with CTI for different fault locations. Whenever a unsymmetrical fault(LL) occurs on the Panchkhal-Banepa transmission line, the relay pairs (R1, R2) acts as primary protection and (R4, R6) as backup protection relays with the operating time of (0.100 s, 0.100 s) & (0.477 s, 0.455 s) respectively, ensuring the coordination time interval of (0.377 s, 0.355 s) for reliable backup protections.

Similarly, when fault occurs on the Indrawati-Panchkhal transmission line and Sunkoshi-Panchkhal transmission line, the relays pairs (R3, R4) & (R5, R6) acts as primary protection relays with operating time of (0.08 s, 0.08 s) & (0.08 s, 0.08 s) respectively. In both cases, R1 acts as backup protection relay with operating time of (0.409 s, 0.395 s), ensuring the coordination time interval of (0.329 s, 0.315 s).

Figure 7 shows the operating time of primary and backup OCRs with the CTI for different fault locations. When a symmetrical fault(LLL) occurs on the Panchkhal-Banepa transmission line, the relay pairs (R1, R2) acts as primary protection relay and (R4, R6) as backup protection relays with the operating time of (0.100 s, 0.100 s) & (0.414 s, 0.403 s) respectively, ensuring the coordination time interval of (0.314 s, 0.304 s) for reliable backup protections.

Similarly, when fault occurs on the Indrawati-Panchkhal

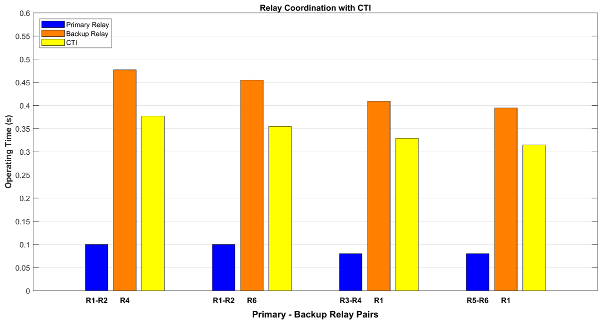

Figure 6. Phase relays operations (LL)

transmission line & Sunkoshi-Panchkhal transmission line, the relay pairs (R3, R4) & (R5, R6) acts as primary protection relays with operating time of (0.08 s, 0.08 s) & (0.08 s, 0.08 s) respectively. Here, at both cases, R1 acts as backup protection with operating time of (0.402 s, 0.377 s), ensuring the coordination time interval of (0.322 s, 0.297 s).

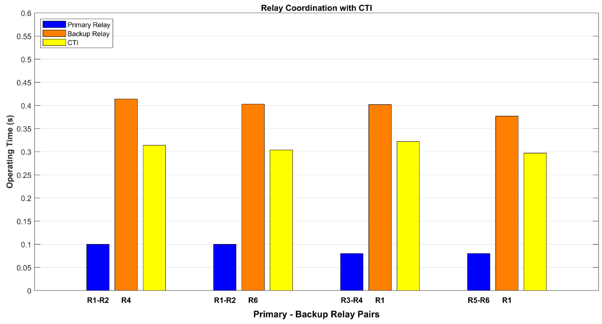

Figure 7. Phase relays operations (LLL)

5.2. Distance-to-Backup OCRs Coordination

Figure 8 shows the impedance diagram and operating time of zone-1 (red) of the D1 distance relay and zone-2 (blue) of the D2 distance relay, whereas Table 2 illustrates the operating time of distance-to-distance and distance-to-backup OCR's for different fault location on the line. For instance, when a symmetric fault occurs on the 15% line length of Panchkhal-Banepa line, than Zone-1 of the distance relay(D2) operates instantaneously and zone-2 of the distance relay(D1) operates with delay of 0.420 s as the fault location fall on the zone-2 of the relay. The backup protection to zone-2 of distance relay(D1) is ensured by operation of backup OCR i.e. R1, with a time delay of 0.712 s. To ensure the CTI between Zone-2 of D2 distance relay and backup OCR(i.e.R1) with 0.292 s. Similarly, when a symmetric fault occurs on the 85% line length of Panchkhal-Banepa line, then zone-1 of the distance relay(D1) operates instantaneously and the location of fault falls in zone-2 of distance relay(D2), it operates with a time delay of 0.420 s. The backup protection to zone-2 of distance relay is ensured by operation of backup OCR i.e. R2, with a time delay of 0.712 s. To ensure the CTI between Zone-2 of distance relay(D2) and backup OCR(i.e.R2) with 0.292 s. In the same manners operating time of distance-to-distance and distance-to-backup OCR's for different fault location on the different lines are summarised in the Table 2.

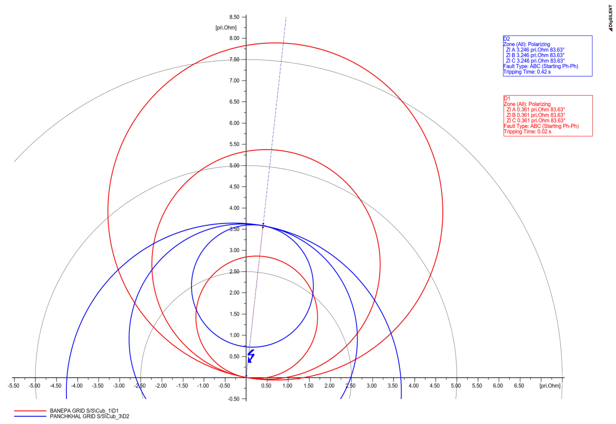

Figure 8. Operation of distance relay

Table 2. Operating time of distance-to-distance and distance-to-backup OCRs

Transmission Line	Fault Location	Main Relay	Main Relay Operation Time(Sec)			Backup Relay	Backup Relay Operation Time(Sec)	CTI (Sec)
			Zone1	Zone2	Zone3			
Panchakhal-Banepa Line	15%	D1	-	0.420	-	R1	0.712	0.292
		D2	0.02	-	-	R2	-	
	85%	D1	0.02	-	-	R1	-	-
		D2	-	0.420	-	R2	0.712	0.292
Indrawati - Panchakhal Line	15%	D3	-	0.420	-	R3	0.714	0.294
		D4	0.02	-	-	R4	-	
	85%	D3	0.02	-	-	R3	-	-
		D4	-	0.420	-	R4	0.716	0.296
Sunkoshi-Panchakhal Line	15%	D5	-	0.420	-	R5	0.724	0.304
		D6	0.02	-	-	R6	-	
	85%	D5	0.02	-	-	R5	-	-
		D6	-	0.420	-	R6	0.717	0.297

6. Conclusion

This study successfully analyzed the protection coordination between distance relays and over-current relays within a section of the INPS. The simulation results for different fault conditions including symmetrical and unsymmetrical faults, demonstrated that primary and backup OCR relays operated with time delay to ensure CTIs in permissible limits to isolate the faults on the system. The zone-2 of the distance relay and backup OCR was also operated with time delays in the permissible CTIs to ensure the coordination between the zone-2 of the distance relay and backup OCR to isolate the faults.

The results confirmed that the current protection settings are capable to provide effective fault detections and isolation of faults, which ensure the reliable operation of the systems considered for the study. However, continuous expansion of the INPS and integration of the renewable energy resources over the time may result in periodic review and updating of the relays. Our future work will focus on study of the larger section of the INPS to investigate and analyse protection coordination strategies of more complex networks.

Acknowledgments

The authors would like to thank the Grid Modernization Laboratory under the Department of Electrical and Electronics Engineering, Kathmandu University for providing academic support during the preparation of this paper.

References

Altuve, H. J., Zimmerman, K., & Tziouvaras, D. (2016). Maximizing line protection reliability, speed, and sensitivity. *2016 69th annual conference for protective relay engineers (CPRE)*, 1–28.

Anderson, P. M., Henville, C. F., Rifaat, R., Johnson, B., & Meliopoulos, S. (2021). *Power system protection*. John Wiley & Sons.

Babu, G. S., Venugopal, S., & Krishna, T. M. (2020). Inverse definite minimum time relay coordination in radial traction system. *International Journal of Electrical Engineering and Technology*, *11*(4).

Bhuvanesh, A. O., Nirmal-Kumar, C. N., Rashesh, P. M., & Vijay, H. M. (2010). Power system protection and switchgear.

Dashti, R., Hassani, S., & Shaker, H. R. (2018). Protection coordination assessment and improvement of electrical network of an industrial complex in connection to power grid: An experience report. *2018 5th International Conference on Electrical and Electronic Engineering (ICEEE)*, 263–268.

Hong, L., Rizwan, M., Wasif, M., Ahmad, S., Zaindin, M., & Firdausi, M. (2021). User-defined dual setting directional overcurrent relays with hybrid time current-voltage characteristics-based protection coordination for active distribution network. *IEEE Access*, *9*, 62752–62769. https://doi.org/10.1109/ACCESS.2021.3074426

IEEE Standard for Inverse-Time Characteristics Equations for Overcurrent Relays [IEEE Std C37.112-2018]. (2018, December). Institute of Electrical and Electronics Engineers (IEEE). Retrieved April 29, 2025, from https://standards.ieee.org/ieee/C37.112/7036/

Jungang, L., Aimin, Z., Hang, Z., Xing, L., & Yingsan, G. (2015). Study of coordination mechanism between protection and control of regional power grid. *2015 34th Chinese Control Conference (CCC)*, 8986–8989.

Khond, S. V., & Dhomane, G. A. (2019). Optimum coordination of directional overcurrent relays for combined overhead/cable distribution system with linear programming technique. *Protection and Control of Modern Power Systems*, *4*(2), 1–7.

Kumar, P., & Rana, A. S. (2024). Review of optimization techniques for relay coordination in consideration with adaptive schemes of microgrid. *Electric Power Systems Research*, *230*, 110240.

Naresh, P., & Sudarshana, R. H. (2020). Optimal over current relay coordination of ieee 9 bus system using mipower. *International Journal of Recent Technology and Engineering (IJRTE)*, *8*(5).

Rahim, M. N. A., Mokhlis, H., Bakar, A. H. A., Rahman, M. T., Badran, O., & Mansor, N. N. (2019). Protection coordination toward optimal network reconfiguration and dg sizing. *IEEE Access*, *7*, 163700–163718.

Singh, M. (2017). Protection coordination in distribution systems with and without distributed energy resources-a review. *Protection and Control of Modern Power Systems*, *2*(3), 1–17.

Singh, M., Telukunta, V., & Srivani, S. (2018). Enhanced real time coordination of distance and user defined over current relays. *International Journal of Electrical Power & Energy Systems*, *98*, 430–441.

Singh, P., Kumar, U., Choudhary, N. K., & Singh, N. (2024). Advancements in protection coordination of microgrids: A comprehensive review of protection challenges and mitigation schemes for grid stability. *Protection and Control of Modern Power Systems*, *9*(6), 156–183.