https://doi.org/10.29227/IM-2025-01-02-035 *Received: 25 Oct 2024, Accepted: 01 May 2025, Published: 01 Sep 2025*

A research of utilizing directional protective device for improving the sensitivity of digital relay in Vietnam coal mines grid

NGUYEN Cong Cuong[1], **NGUYEN Huyen Trang**[2*], **LE Xuan Thanh**[3], **HO Viet Bun**[3]

[1] HaNoi University of Industry, Hanoi, Vietnam
[2] Viet-Hung Industrial University, Hanoi, Vietnam
[3] Hanoi University of Mining and Geology, Hanoi, Vietnam
[*] *Corresponding email: nguyenhuyentrang@viu.edu.vn*

Abstract: *As mining activities and productivity escalate, the 6kV power grid infrastructure of open-pit mines has become increasingly diverse in load types and structurally complex. Consequently, the demands placed on relay protection systems are progressively intensifying. Beyond merely ensuring operational safety, these systems are now required to enhance power supply reliability, thereby minimizing interruptions that could severely disrupt the production cycle. Notably, none of Vietnam's open-pit mines currently utilize directional Over-current relay (DORC) in their 6kV feeders. Because of including electric excavators, the power running to the fault point in 6kV PCC node could come from two direction causing the wrong operating of over-current relays Thus, the utilizing the directional protector is critically important for bolstering the reliability and efficiency of the power supply system in these mining operations. The devices automatically detect not only fauls current value but also their direction, then isolate the fault point after predefined delay. This mechanism significantly reduces the wrong tripping in 6kV grids from earthing as well as one-phase short-circuited, which account for over 80% of total faults MV grids of mines. This paper, through a study of the characteristics of medium-voltage grids with electric excavators as distributed loads, proposes an effective directional relay application. The synchronization of setting parameters of multi-level DOCR (3levels) is also proposed, supported by thorough simulation and verified utilizing ETA and NEPLAN software, to prevent premature relay operations (false trips), which could lead to unnecessary power outages and prolonged supply interruptions. The integration of directional protector within the framework of overcurrent protection, combined with well-calibrated adjustments, will be validated with a specific 6kV power grid of a coal mine to demonstrate the feasibility and effectiveness of the proposal. The outcome setting values are customized with grids' internal parameter to perform a discriminative tripping. These ones are also used to recommend their application across all medium-voltage grids in Vietnam's coal mines.*

Keywords: *directional overcurrent relay; open-pit mines; contrary power flow; contrary power flow; Time-Multiplier-Setting (TMS)*

1. Introduction

1.1. The Role of Over-Current Relays (ORC) in 6kV VietNamese coal mines' grid

Because of mining stages requirements, the structure of 6kV mining grids are mostly skeleton configuration. Due to containing multi-ladder mining sections, the grid must have multi-level protection relays. Therefore the Over-Current Relays are extensively employed in the medium-voltage distribution networks of 6kV mining systems.

Normaly, the deployment of overcurrent protection devices, such as 50, 51, 50N, and 51N relays at the line entrances, is of paramount importance for fault isolation, thereby mitigating the risk of widespread equipment damage. The implementation of those kind of relay provides several notable advantages, including:

+ **Ease of Implementation**: Overcurrent relays are relatively simple to install and configure, making them highly suitable for protecting radial networks in a cost-effective manner. Studies have emphasized their ease of deployment and configuration, particularly in legacy and modern grids, showing their ability to reduce fault-induced disruptions [19, 26]. This simplicity also allows for a streamlined integration into existing power networks, further enhancing their practicality [16].

+ **Rapid Fault Detection and Isolation**: The relays detect and isolate faults quickly, enhancing system reliability by reducing the risk of equipment damage. Research shows that these relays reduce fault-clearing time significantly, improving the overall safety and continuity of the system [15,29]. Studies also highlight that faster fault detection mitigates the potential for cascading failures [21, 30].

+ **Coordination Flexibility**: Overcurrent relays are highly compatible with other protective devices, including reclosers and fuses, allowing for selective fault clearing without unnecessary shutdowns of unaffected parts of the network. Research of [7, 22] has demonstrated that proper coordination of overcurrent relays with other protection mechanisms enhances the overall reliability and efficiency of power systems. This flexibility ensures that relays can be tailored to specific system configurations for optimized performance [4, 31].

+ **Comprehensive Fault Coverage**: Overcurrent relays provide protection against a wide range of fault types, including phase-to-phase and phase-to-ground faults. Moreover, the efficacy of these relays in ensuring complete fault coverage, making them essential for medium-voltage network protection [18, 32]. Their ability to handle various fault conditions has been proven in numerous field applications [14, 30].

+ **Scalability Across Systems**: Overcurrent relays are highly scalable, which makes them suitable for both small and large distribution systems. Their scalability allows for effective application in diverse environments, including industrial and mining operations, as emphasized in research on power systems scalability [7, 21]. Furthermore, studies have noted the ease with which these relays can be expanded and adapted to meet the needs of growing power networks [22, 29].

+ **Minimal Maintenance Requirements**: Once installed, overcurrent relays require minimal maintenance, contributing to long-term operational reliability. Studies show that these relays, due to their robust design, remain reliable over extended periods without the need for frequent maintenance, reducing the total cost of ownership [14, 21]. This low-maintenance requirement is particularly beneficial in remote or harsh environments, such as mining [16, 19].

+ **Adaptability to Load Variability**: Overcurrent relays can be calibrated to accommodate varying load conditions, making them ideal for dynamic environments such as mining operations. They are also easily adjustable to match changing load patterns, which is crucial in sectors where demand fluctuates significantly [1, 3, 25]. Their adaptability ensures reliable protection across a wide range of operating conditions [1, 7].

+ **Equipment Lifespan Extension**: By promptly isolating faulted sections, overcurrent relays prevent equipment from being exposed to sustained fault currents, thereby extending the operational lifespan of electrical components [3, 7]. Additionally, this protection capability results in improved asset management and reduced replacement costs [18].

+ **Instantaneous Response to Severe Faults**: Overcurrent relays can respond instantaneously to severe fault conditions due to their instantaneous tripping settings, which ensures rapid fault clearing and improved system stability. This capability is critical for preventing high-magnitude faults from causing widespread damage [29, 31]. This feature also enhances the overall fault-clearing performance of the relay system [21, 31].

+ **Cost-Effectiveness**: The relatively low cost of overcurrent relays, combined with their robust protection features, makes them an economically viable solution for medium-voltage networks. Numerous studies have highlighted the cost-efficiency of these relays in reducing fault-related downtimes and preventing expensive system failures [4, 17]. The widespread adoption of overcurrent relays in modern power systems is a testament to their economic and operational benefits [26, 29].

Because of above mentioned extensive advantages, 100% Vietnam coal mine 6kV utilize OCRs as essential protectors for 6kV feeders including both overhead lines and cables. However, through the fact operation, OCRs still have some problem of discriminative tripping. The fact of their disadvantages will be discussed in the next part of paper.

1.2. Disadvantages of OCR and the need of employing Directional Over-Current Relays (DOCR)

Because of the containing multi-level tripping, the operation of 6kV feeders OCRs has many disadvantages, particularly the wrong tripping could sometimes arise that lead to big economical damage caused by de-energizing process. Some main advantages of ORCs in 6kV Vietnam coal mines grids are [6, 34]: Delayed response time; Discriminative tripping/Inaccurate coordination; limited sensitivity and lack of directional sensing. In table 1, base on surveying data of 6 main coal mines in VietNam, 4 of them obtain relay discriminal tripping.

Tab. 1. Summary of discriminative tripping problem in operation of 6kV OCRs in VietNam [6]

Name of	Tripping time before applying	Discriminative	Tripping time after applying	Number of protection

coal mines In VietNam	**TIA (s)**	**problem**	**TIA**	**zones**
HaLam	16	YES	0,862	2
NuiBeo	15	NO	2,063	3
ThongNhat	20	NO	0,968/	2
CaoSon	22	YES	1,267	3
CocSau	16	YES	1,689	3
QuangHanh	18	YES	2,078	3

Most of OCRs' indirectional sensing could results to the incorrect tripping during faults heppenning on the non-protected side, causing to inefficient fault isolation and leading to potential damage of parts of the system. In underground coal mines, those matter is insufficient because of grid's structure, power flow is running in only one direction routine, but in open-pit coal mines whereas inversed powerflows of 6kV electric excavators exhibits as distributed generator, the matter is significantly considered. Moreover, earthing currents in 6kV grids (accounting nearly 90% of the total fault) is not great enough for initiating the tripping signal of the relays. Figure 1 shows the routine of earthing current which might be so small that the OCRs can not be initiated.

Many researches [2], [8-10] presents the chalenges of calculating the setting values as well as determining the time parameters, selecting tripping curves of OCRs [13], [23-24], [27]. Many methods might be used for computing/optimizing these quantities, but using directional over-current relays (DOCR) combine with the Optimizers to calculate/select appropriate time curves is still the most effective solution [3], [11-13], [20].

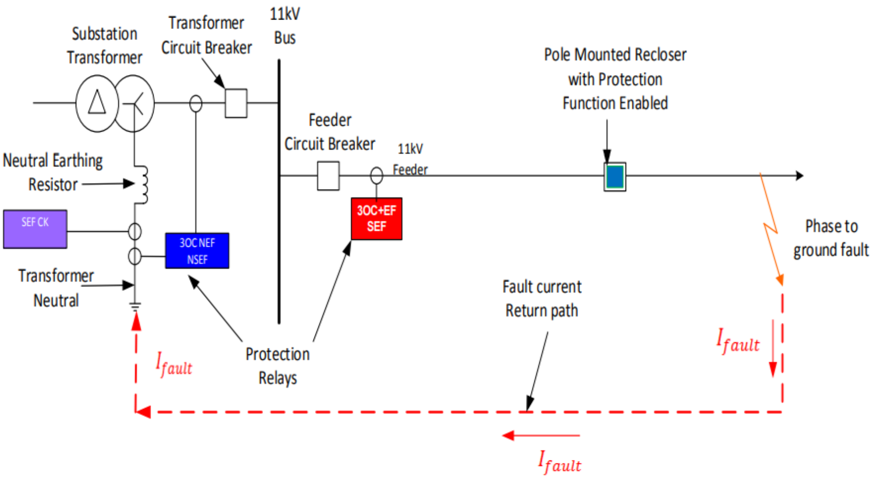


Fig. 1. Direction of earthing current in 6kV MV grids

As presented in figure 2, 3 [28] the electric excavators of open pit-mines inject huge amount of inversed energy to the source. In over-excitated mode, they exhibit like distributed generator that cause to the lack of directional sensing in operation of OCRs themselves. The power flows of the grids with over-excitation excavators is shown in figure 4.

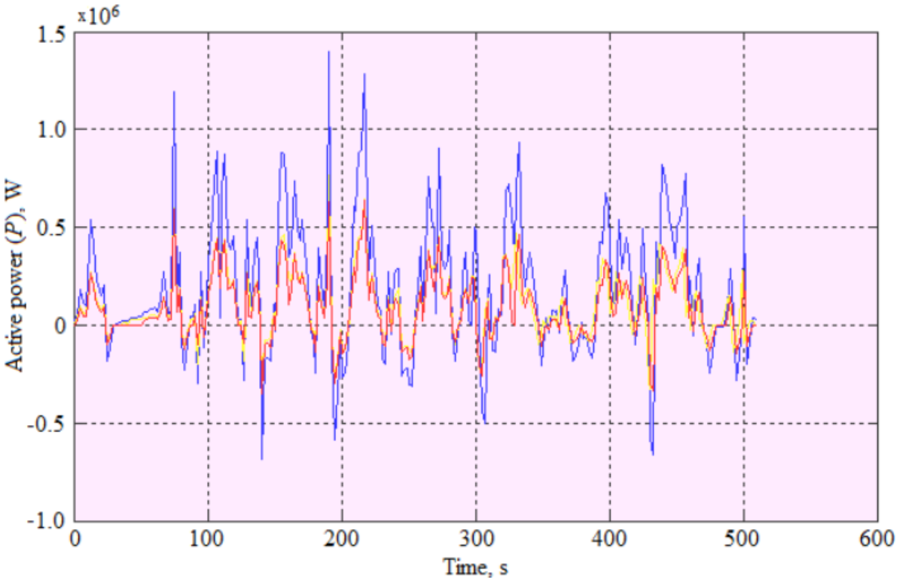


Fig. 2. Inversed active power flows of electric-excavator injected to grids (CaoSon coal mines)

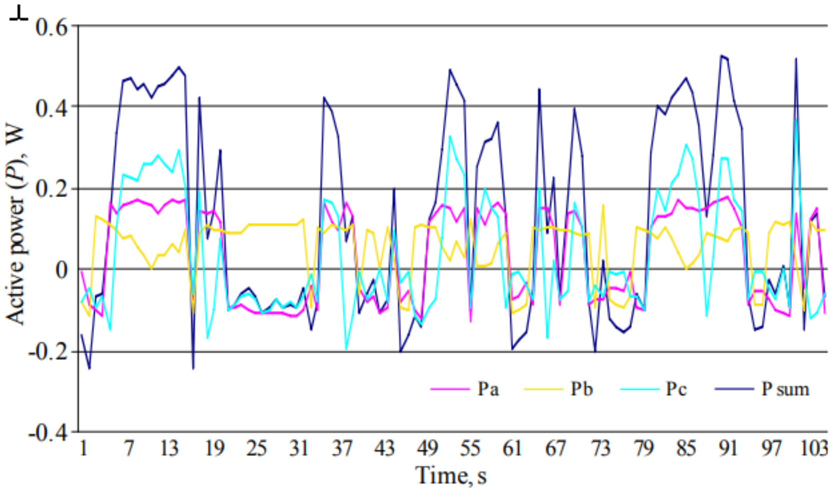


Fig. 3. Inversed active power flows of electric-excavator injected to grids (CocSau coal mines)

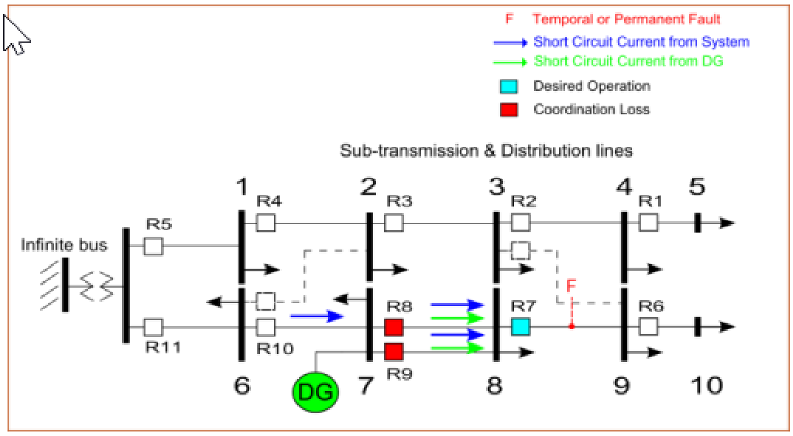


Fig. 4. Pefomrmance of power flows of overexcited e-excavators as distributed generators

The following parts, the paper exhibit an modified algorithm utilizing both Gurobi Optimizer and Harris Hawk Optimization [20] for coordinating the operation of DOCRs in 6kV feeders of Vietnam coalmines.

2. Theoretical background about Directional Over-Current relay, an observation from a system perpective

Normally, a DOCR (67) is equiped at the beginning end of a feeder. In a skeleton feeder, the relays is designed parallely with a current transformer (CT) containing polarity mark. A simple expression of

DOCR is presented in figure 5, the phasor diagram [11] of the DOCR connected to circuit breaker 3 and 4 are shown in figure 6 and 7.

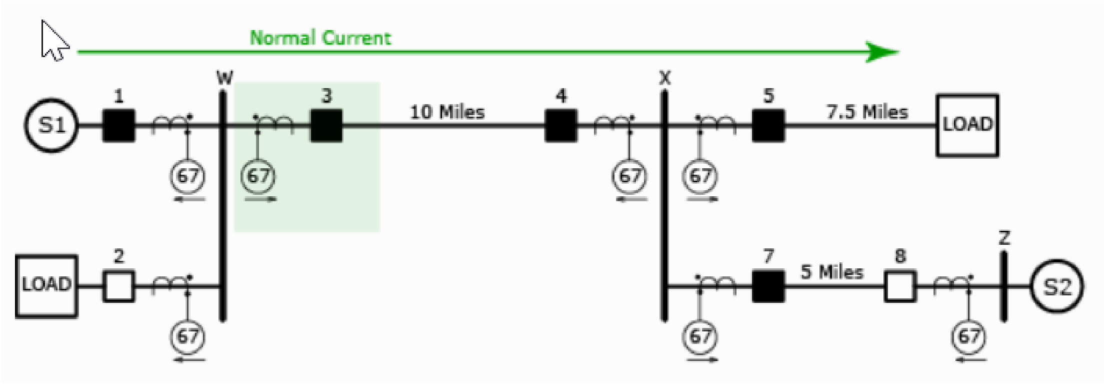
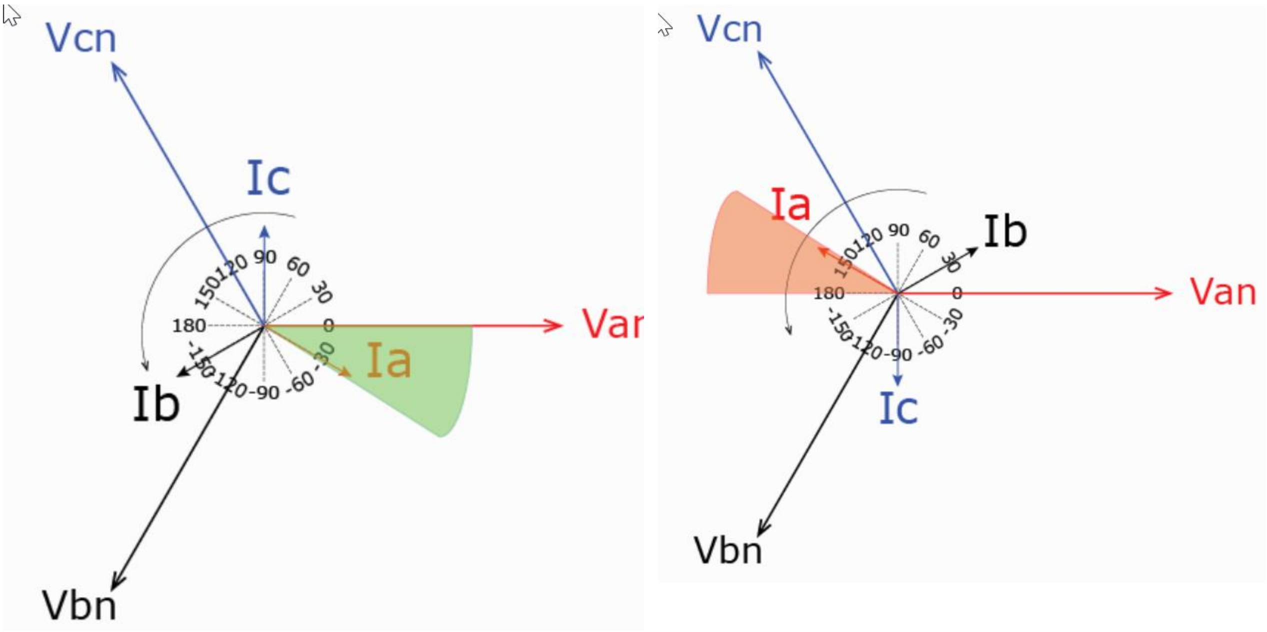


Fig. 5. Single line diagram of a grid including DOCR (67) with polarity of CT



a) **b)**

Fig. 6. Phasor diagrams of DOCR connected to CB3 and CB4

Obviously, current is flowing in the reverse direction (b) ans the orange shaded area displays the normal region as current “supplied” to the load behind the relay [11] . If CB8 (in figure 5) is closed, at this time the fault occures between CB3 and CB4, the short-circuited current should lag the voltage by 40 to nearly 90 degrees depending on grid’s parameters. The direction of fault current is presented in figure 7. Because of CTs’ polarity, both CB3 and CB4 will “recognize” that current is in forward direction. The phasor diagram of both relays is exhibited in figure 8, whereas the typical region is in green area.

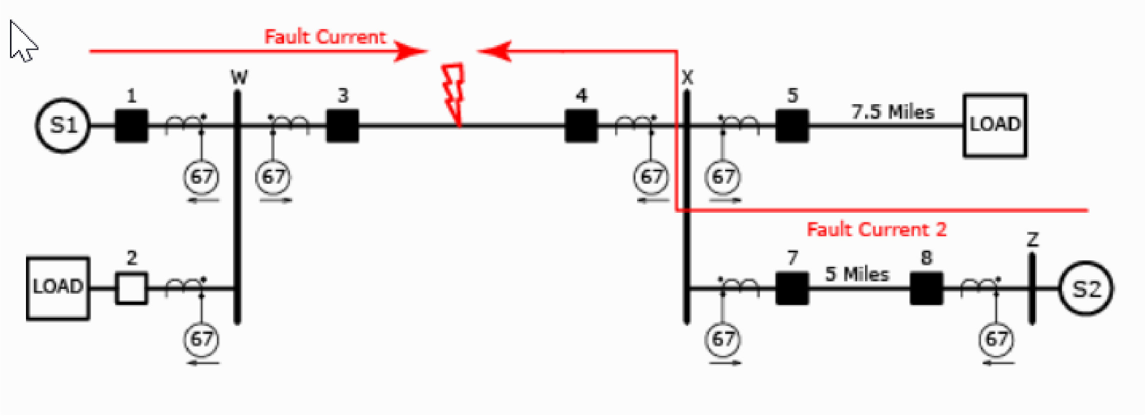


Fig. 7. Single line diagram of 2 sources grid protected by DOCRs

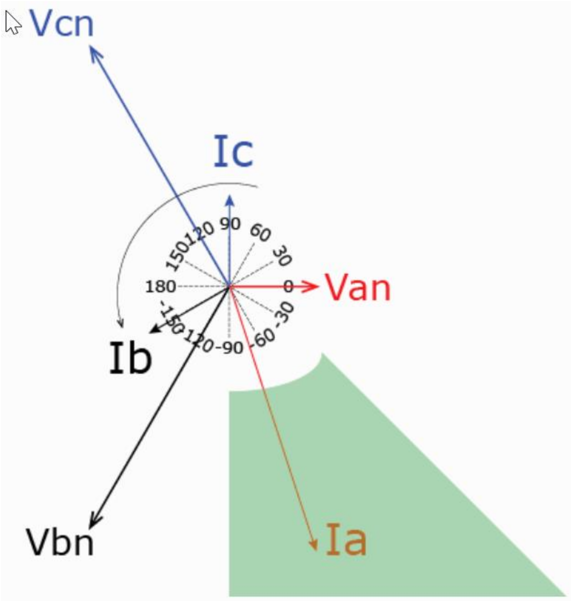


Fig. 8. Phasor diagrams of DOCRs connected to CB3 and CB4

Notably, “Overcurrent directional relays can be set to trip for faults in the forward direction, which will protect the equipment in front of the relay. Or they can also be set to trip for faults behind the relay in the reverse direction. Forward and reverse are typically determined by the normal flow of current into the relay, so be sure to confirm the CT connections “ before making any assumptions [11].

3. Methodology

3.1. Computing setting parameters of relays

As mentioned in [5-7], [11], [17], [19] for obtaining discriminative tripping, TMS-Time Multiplier Setting must be essential parameters identified [33, 34]. The value as wel as time ladding interval (Δt) of DOCRs proper determined could avoid the wrong tripping (backup DOCR trips before essential DOCR. Many researches proposed Linear Programming Algorithm which is embeded into Gurobi Optimizer in ETAP software for testifying. According to [1], [6], [11] the following expression show the calculation of DOCR tripping time installed in skeleton feeder. This one is computed as following equation (1):

$$t = \frac{0{,}14}{(I_{nm}/I_s)^{0{,}02} - 1}.TMS \quad (1)$$

Whereas: I_{nm}-3-phase short cirtcuit current;

I_s-Setting value.

For identifying the value of TMS, a Linear Programme Algorithm is applied [1], [6] in which an objective function f(x) (equa. (2)) is solved to obtain its minimum value, the constraint of the function is shown in equation (3) [6].

$$f(x) = \sum_{j=1}^{n} c_j x_j \rightarrow \min \quad (2)$$

$$\sum_{j=1}^{n} a_{ij} x_j = b_i; \quad x_j \geq 0 \, (3)$$

Where:

a_{ij} is the element of constraint matrix A;

b is the vector of freedom parameter;

x = (x1, x2,..xn) is the optimal results of equation (2) which meet the constraint (3).

3.2. Constraints of Objective Function and Propose of Algorithm

For satisfying the discriminative tripping, other constraints are considered:

Additional constraint 1: time bias between essential OCR (T_{iN}) and back up (T_{jN}) when there is a fault at N.

$$T_{jN} - T_{iN} \geq \Delta t \Rightarrow K_{jN}TMS_j - K_{iN}TMS_i \geq \Delta t \quad (4)$$

Additional constraint 2: TMS of each relay:

$$TMS_{min\_i} \leq TMS_i \leq TMS_{max\_i} \quad (5)$$

Additional constraint 3: TMS must be in the range of T_{min_i} and T_{max_i} which are listed in specification of each OCR:

$$T_{min\_i} \leq T_i \leq T_{max\_i} \quad (6)$$

If the time-curve characteristic is Definite Time (DT) or Inverse definite minimum time (IDMT), Objective function f(x) epressed in (1) is solved as:

$$\min C = \sum_{i=1}^{n} t_i = \sum_{i=1}^{n} K_{iN} TMS_i \quad (7)$$

As indentified in [20] aboved TMS (in equation (5)) must be in the range of (0,1 to 1,1). Basing on above equations, an modified algorithm is proposed in figure 9 with consideration of allowance TMS limits.

4. Results and discussion

A single line diagram of Vietnam coalmines 6kV grid shown in figure 10 is simulated in NEPLAN for obtaining values of short-circuit currents. The values are utilized for setting up the relays as well as verifying the sensitivities itself.

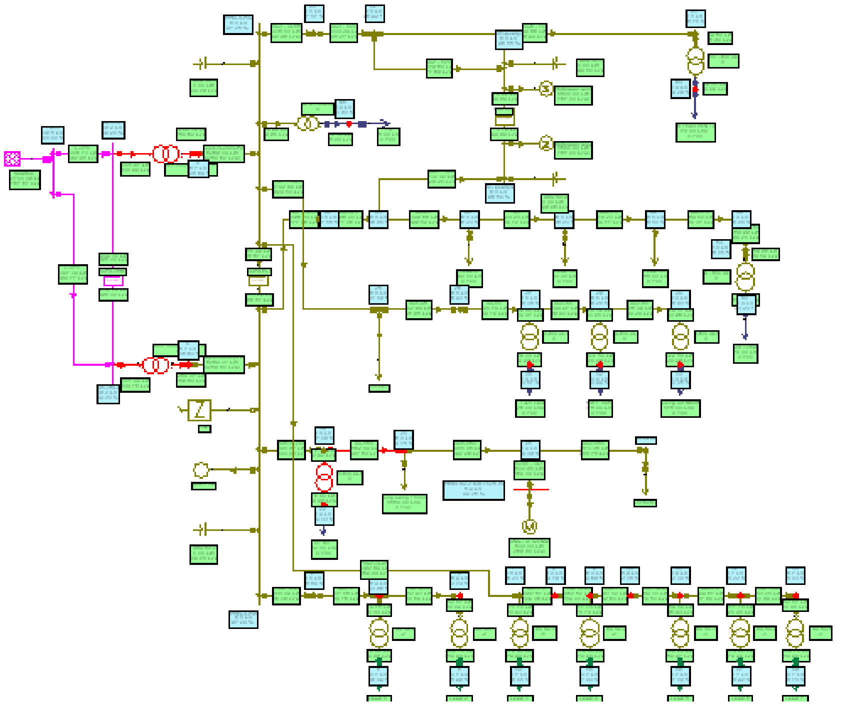


Fig. 10. Simulation of 6kV grid to obtain values of short-circuit currents

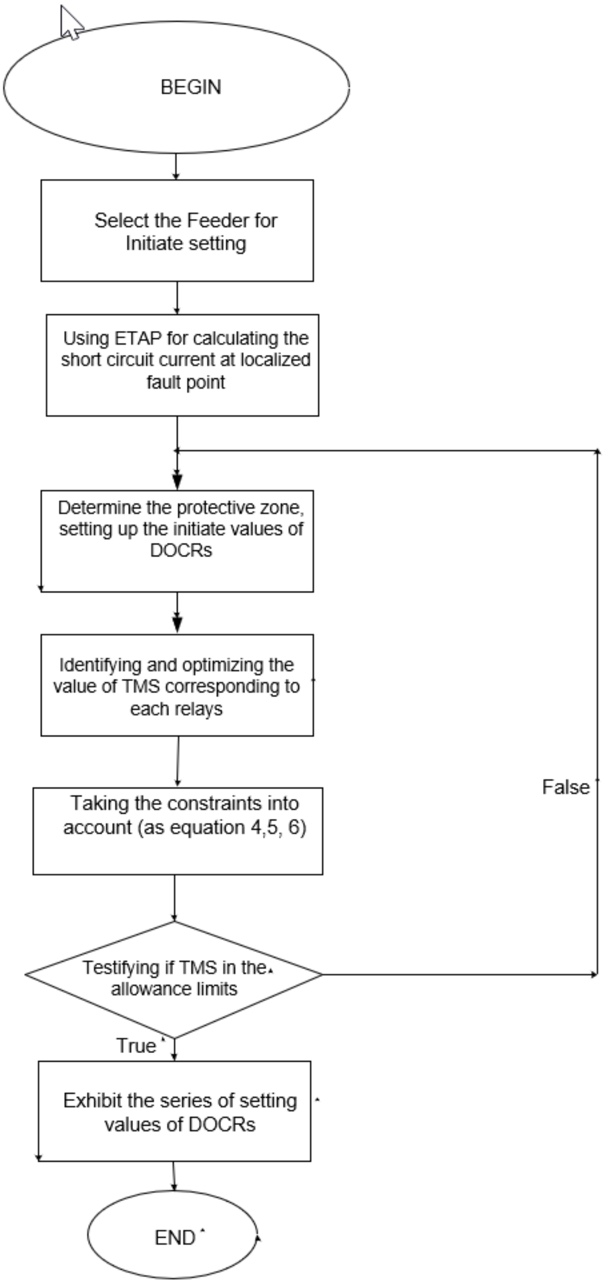
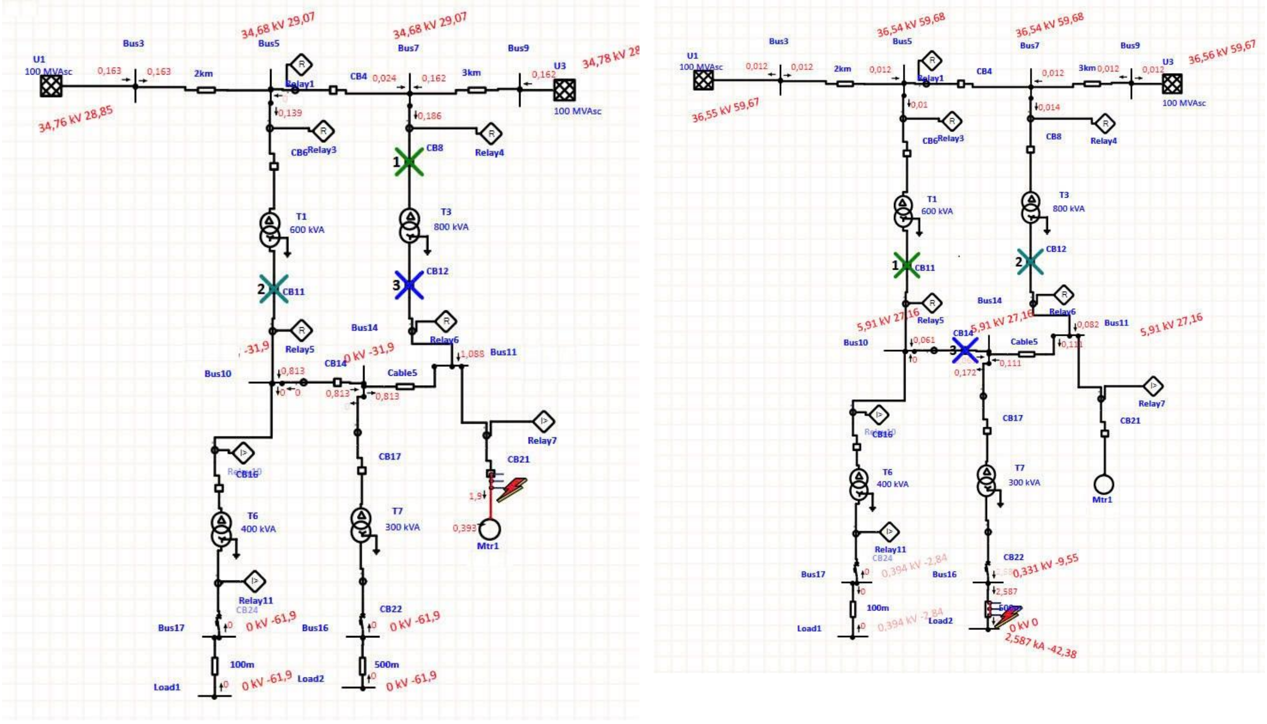


Fig. 9. Block Algorithm presenting the Optimal calculation of TMS for DOCRs

Base on the diagram in figure 10, a simplized grid is simulated in ETAP which presents the operation and tripping of circuit breakers when relay is not optimized.

+ In figure 11a, short circuit point is under CB12, the right tripping order must be CB21>CB12>CB11>CB8 (from downstream to upstream), but as can be seen in the figure, the backup relay of CB8 is active first, next is relay of CB11. Consequently, all of the loads in 6kV grid is de-energized.

+ Similarly, in figure 11b, when the branch of transformer T7 downstream is short-circuited, the fault must be isolated from the left side, the order tripping must be CB14>CB12>CB11. However, as shown in the figure CB11 is operated first, this make all load of grid is de-energized.



a) **b)**

Fig. 11. The expression of discriminative tripping because of inverse power flow

Ploting the operational curves of the relays, results are exhibited in figure 12 and 13.

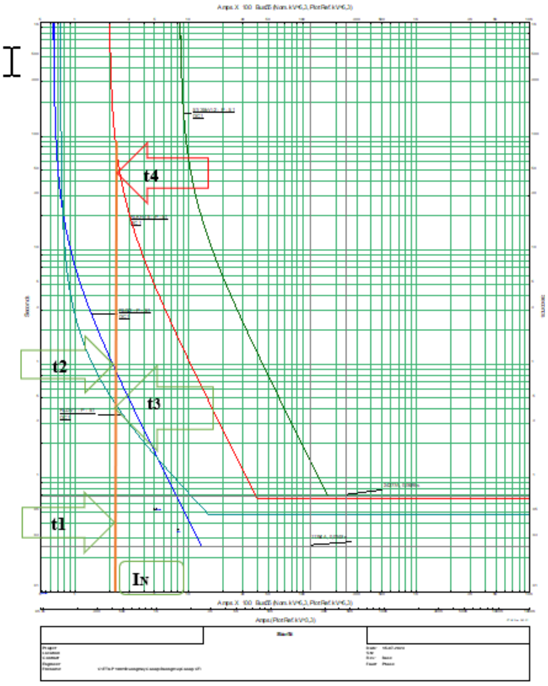


Fig. 12. Plot figures of relays' characteristics showing the problem of discriminative tripping

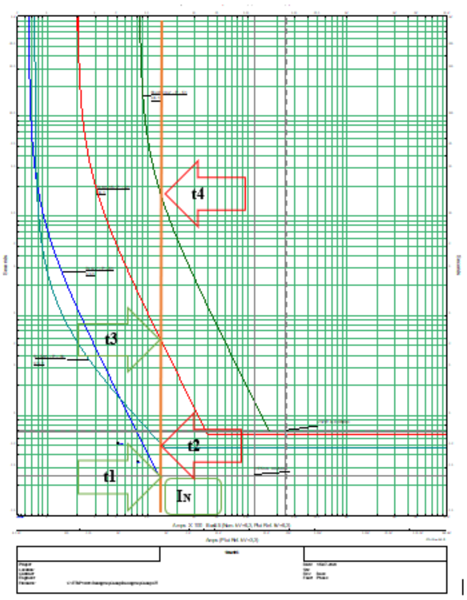


Fig. 13. Plot figures of relays' characteristics performing the discriminative tripping

As presenting in figures 12, when there is reverse power flow, computing the TMS values is fulfiled but tripping time of relays is incorrect because of IDMT curve overlap, hence, the operating time is chaos. In constrary, the figure 13 exhibites the discriminative tripping, the first tripping level, DOCR relay has definite time (t1 ≈ 0), other backup relays performed ascending trip from downstream to upstream. This relays' logical operation advoid wrong isolation the healthy parts of the grid. For improving the operation of relays performing the characteristics in figure 12, applying the DOCR with optimal procedure in figure 9, acccording to the CT allocation, the plot graph of relays is presented in figure 14.

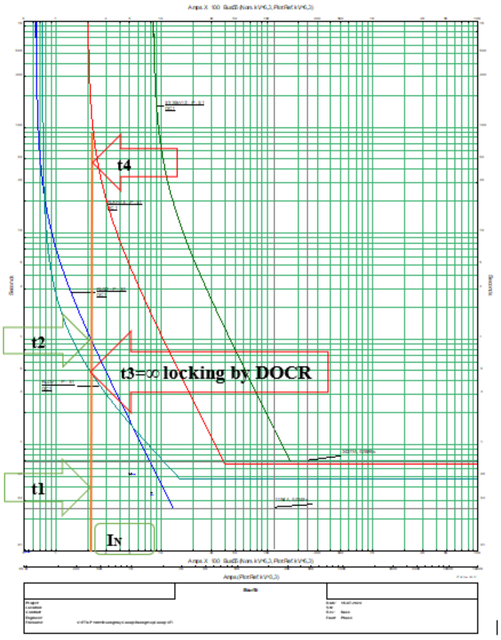


Fig. 14. Plot grapth of relays' characteristics performing the effectiveness of DOCRs

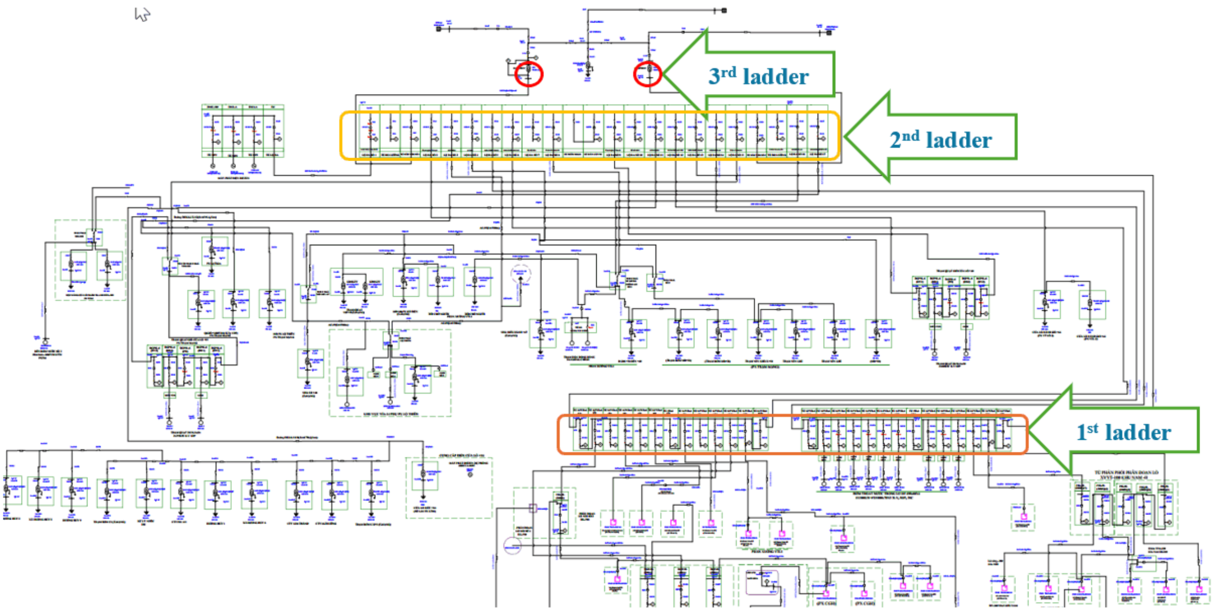


Fig. 15. Diagram of 6kV grid including 3 ladder DOCRs

Simulating the responces of DOCRs of the whole system with the elemination of 4th ladder at 35kV side (corresponding to t4 in figure 12, 13, 14), the network is shown in figure 15 including "3 ladder tripping" relays. Implementing the same process like mentioned above, applying the optimal algorithm, base on the grids' parameters, the results of TMS calculation (programmed in Matlab [6]) is summerized in table 2. Table exhibits the outcomes of 3 feeders containing reverse power flows.

Tab. 2. Outcome calculations of 3 feeder equiped with and without DOCRs

No of Feeder	Status of feeder	**TMS**			Checking the Limit of TMS	Status of discriminative tripping
		Primary relay (at 1st ladder)	Back up 1 (at 2nd ladder)	Back up 2 (at 3rd ladder)		
1	With DOCR	0,203	0,532	0,817	Satisfied	Satisfied
	Only OCR	0,253	0,646	0,521	Satisfied	**Unsatisfied**
2	With DOCR	0,412	0,674	-	Satisfied	Satisfied
	Only OCR	0,376	0,813	1,216	**Unsatisfied**	Satisfied
3	With DOCR	0,324	0,51	0,786	Satisfied	Satisfied
	Only OCR	0,415	0,835	0,765	Satisfied	**Unsatisfied**

The results in the table 2 proved that: if the feeder includes reverse power flows, using only ORC might cause either the violation of TMS (not fall in the range of (0,1 to 1,1 [20]) or having the problem of discriminative tripping. By applying DOCR with the consideration of proposed optimal algorithm, the relay system in all testified feeders are operated well by both above mentioned criterias.

5. Conclusion

By applying the programming in Matlab, optimized and combined with simulation in ETAP and NEPLAN based on proposed TMS Identification Algorithm for DOCRs, the paper obtain the series of TMS values for DOCRs and performed the following conclusions of utilizing these kind of relays in 6kV grid of VietNam coal mines:

+ The examined grids obtain the discriminative tripping problem if the feeder contain reverse power flow. If only equiped OCR the values of TMS might violate the limits, and some circuit breaker might be tripped open inappropriate cause to the isolate of healthy part of grid;

+ Operator/technician in mine must take into account the wrong tripping of overcurrent relay using IDMT characteristic, the combiantion of series of relays' characteristics could lead to malfunctioned operate of OCRs;

+ The problem of either delayed-tripping or discriminative tripping are totally cleared with application of DOCRs in specific feeder of 6kV grid of coal mines in VietNam.

+ Method proposed in the paper using ETAP are visualable for operating and designing the DOCRs system in 6kV grids in the very beginning stages.

Literature - References

1. A. A. S. Mohamed and T. K. A. Rahman, "Adaptive Overcurrent Protection Scheme for Distribution Networks with DG Penetration," *IEEE Transactions on Industrial Electronics*, vol. 67, no. 6, pp. 4827-4836, 2020
2. A. Zamani, T. Sidhu, and A. Yazdani, "A Strategy for Protection Coordination in Radial Distribution Networks with Distributed Generators," in *Proceedings of the IEEE Power Energy Society General Meeting*, pp. 1-8, 2010
3. A. Oudalov and A. Fidigatti, "Adaptive Network Protection in Microgrids," *International Journal of Distributed Energy Sources*, vol. 5, no. 3, pp. 201-225, 2009
4. Almeida, R., & Silva, L. (2020). *Economic analysis of protective relay technologies in medium-voltage networks*. IEEE Transactions on Energy Economics, 35(7), 612-620
5. B. Hussain, S. M. Sharkh, S. Hussain, and M. A. Abusara, "An Adaptive Relaying Scheme for Fuse Saving in Distribution Networks with Distributed Generation," *IEEE Transactions on Power Delivery*, vol. 28, no. 2, pp. 669-677, 2013
6. Bun Ho Viet, Thanh Le Xuan "A new approach on improving the operation of Overcurrent relays in 6kV mining Grids of QuangNing, VietNam" INZYNIERIA MINERALNA Journal of the Polish Mineral Enginerring Society, vol. 2, issue 52, pp. 29-38, 2023
7. Chen, Y., Wang, Z., & Li, Q. (2021). *Scalability of protective relay technologies in industrial applications*. IEEE Industrial Electronics Magazine, 15(2), 42-50
8. D. A. Tziouvaras, "Protection Challenges in Distribution Networks with High Penetration of DGs," in *Proceedings of the 68th Annual Conference for Protective Relaying*, pp. 210-219, 2015
9. E. O. Schweitzer and D. E. Whitehead, "Real-World Synchrophasor Solutions," in *Proceedings of the 63rd Annual Georgia Tech Protective Relaying Conference*, Georgia, USA, Apr. 2009, pp. 1-12.
10. G. Antonova, M. Nardi, A. Scott, and M. Pesin, "Distributed Generation and Its Impact on Power Grids and Microgrids," in *Proceedings of the 65th Annual Conference for Protective Relaying*, pp. 152-161, 2012
11. "Finding the Direction in Directional Overcurrent relays," *Valence Electrical Training Services*, Internet access on 21.10.2024 https://relaytraining.com/finding-directional-overcurrent/?srsltid=AfmBOopW2ir9vahWYlasxkuJSYhP_sKntV9zpx3dq__cEuhaEOGqLfUf
12. H. Laaksonen, "Protection Principles for Future Microgrids," *IEEE Transactions on Power Electronics*, vol. 25, no. 12, pp. 2910-2918, 2010
13. H. Z. De La Parra, J. I. Perez and R. I. Zamora, "Impact of Distributed Generation on the Performance of Protective Relays," in *Proceedings of the 20th IEEE International Conference on Emerging Technologies and Factory Automation*, pp. 187-192, 2015
14. Huang, X., Zhao, Y., & Feng, S. (2019). *Extending equipment lifespan through optimized fault isolation*. International Journal of Energy and Power Engineering, 58(4), 522-530
15. Jones, M., & Patel, D. (2018). *Enhancing system reliability through rapid fault detection*. Journal of Electrical Engineering, 45(2), 98-107
16. Jones, M., Taylor, R., & Lee, A. (2017). *Advancements in cost-effective power system protection*. IEEE Transactions on Power Delivery, 32(3), 2302-2309
17. K. I. Jennett, C. D. Booth, F. Coffele, and A. J. Roscoe, "Investigation of the Sympathetic Tripping Problem in Power Systems with Large Penetrations of Distributed Generations," *IET Generation, Transmission & Distribution*, vol. 9, no. 4, pp. 379-385, 2015

18. Kim, H., Cho, S., & Lee, J. (2020). *Fault protection in power networks: The role of overcurrent relays in modern grid infrastructures*. International Journal of Electrical Power & Energy Systems, 117, 105620
19. Kumar, A., & Yadav, P. (2018). *Protection strategies for modern power grids: A review of overcurrent relays*. Journal of Power and Energy Systems, 24(1), 58-70
20. Muhamad Irfan, Seung-Ryle Oh, Sang-Bong Rhee "*An Effective Coordination Setting for Directional Overcurrent relays Using Modified Harris Hawk Optimization*," *Electronics*, 10 (23), 2021
21. Nguyen, T., & Tran, K. (2017). *Reliability assessment of overcurrent relays in power systems*. Journal of Power Engineering, 34(3), 210-218
22. Rao, S., & Gupta, P. (2019). *Selective coordination in power distribution systems using overcurrent relays and reclosers*. IEEE Power Systems Conference, 123-130
23. R. A. Walling and N. W. Miller, "Distributed Generation Islanding—Implications on Power System Dynamic Performance," in *Proceedings of the IEEE Power Engineering Society General Meeting*, vol. 2, pp. 26-29, 2003
24. R. M. Ciric, R. W. Dunn, and N. A. Tan, "The Impact of Distributed Generation on Power System Protection and Fault Levels," *International Journal of Electrical Power & Energy Systems*, vol. 43, pp
25. S. M. Brahma and A. A. Girgis, "Development of Adaptive Protection Scheme for Distribution Systems with High Penetration of Distributed Generation," *IEEE Transactions on Power Delivery*, vol. 19, no. 1, pp. 56-63, 2004
26. Smith, J., Taylor, R., & Lee, A. (2016). *Cost-effective protection strategies in medium-voltage grids: A comparative study*. IEEE Transactions on Power Delivery, 31(4), 2450-2458
27. S. Patil and M. Bollen, "Impact of Distributed Generation on Power Quality and Protection," *IEEE Transactions on Power Delivery*, vol. 21, no. 1, pp. 524-530, 2006
28. Le Xuan Thanh, Ho Viet Bun "Identifying the factors influencing the voltage quality of 6kV grids when using electric excavators in surface mining," *Journal of Mining of Mineral Deposit*, vol. 16, issue 2, pp. 73-80, 2021
29. Wang, T., Liu, X., & Zhou, M. (2020). *Instantaneous tripping settings in overcurrent protection: Enhancing fault-clearing efficiency*. IEEE Transactions on Smart Grid, 11(1), 150-159
30. Zhang, W., & Lee, C. (2018). *Overcurrent protection in mining environments: Adaptive solutions for dynamic load conditions*. Mining Electrical Systems Review, 12(1), 87-95.
31. Zhao, Y., Huang, S., & Li, F. (2019). *Coordination of protective relays in power distribution systems: Methods and challenges*. IEEE Transactions on Power Systems, 34(2), 842-850.
32. Zhou, P., Li, H., & Wang, J. (2019). *Overcurrent relay-based protection schemes for smart grids*. Journal of Electrical and Computer Engineering, 16(3), 291-301
33. Overcurrent relay and its characteristic, Electrical concept, Internet access at https://electricalbaba.com/over-current-relay-and-its-characteristics/
34. R. R. Williams, G. Benmouyal, and A. D. Singh, "Understanding overcurrent coordination curves," IEEE Transactions on Power Delivery, vol. 17, no. 3, pp. 724-729, July 2002