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Table of Contents

IDENTIFYING SOLUTIONS FOR ENHANCING ELECTRICAL SAFETY IN UNDERGROUND MINES BY ANALYZING PARAMETERS INFLUENCE ON LEAKAGE CURRENT

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Abstract: Recent years, electric safety in underground mining is one of top leading priority in manufacturing management of VietNam coal mines. It covers a wide range of areas, including the extraction of coal resources, residential infrastructure, commercial establishments, and public facilities. Because of applying modern and advanced technologies as well as high-tech apparatus, the structure of underground mining networks becomes more complex with higher rated voltage. One key aspect of electrical safety in Vietnam is the adoption of international standards and best practices, particularly those outlined in the International Electrotechnical Commission (IEC) standards. These standards serve as a foundation for the development of Vietnamese electrical safety requirements and help ensure compatibility and interoperability with global electrical systems. To meet this standard, leakage relays working on leakage current in underground mines must operate securely and reliably, hence understanding deeply the parameters influencing on leakage currents is necessary and important. By analyzing all possible structures in low voltage grids of underground mines in VietNam, the paper will identify the most impact parameters which influence on rms of leakage current for generous observation. Some technical solutions will also be proposed for improving the electrical safety which obtaining the reduce of leakage current. The outcomes computing the values of the current will be implemented in MATLAB for verifying the proposed solution.

1. INTRODUCTION ABOUT ELECTRICAL SAFETY IN UNDERGROUND MINES OF VIETNAM

In Vietnam underground coal mines, there are more and more advanced and modern electrical devices are equipped for serving faster and better the demand of increasing coal productivity. The great number of connected apparatuses to main 6kV/660V transformer substation causes changes in the grid's structure and parameters, which also introduces the risk of electrical hazards for electricians [11]. Most electrical networks feature a leakage protection relay, commonly known as УАКИ, installed in the substation. This relay must activate whenever a leakage current occurs within the 660V grid, and its signal is transmitted to the switching protective device, a low-voltage circuit breaker located at the start of the 660V outgoing feeders. Figure 1 illustrates a typical diagram of a 660V electric power system supplying energy to an underground mine area, displaying the connection of the transformer and the leakage relay. Figure 2 exhibits the connection of the relays with 2 separate earthing rods spaced 5m apart.

Not only Vietnamese requirements, but also international ones [1-7], the electrical safety in mining (in specific) and in industry (in general) is the top priority that all the managers must concern. Enhancing electrical safety in underground mines in Vietnam is of paramount importance due to several following critical reasons:

+ Worker Safety: The primary concern is the safety of underground mine workers. Electricians and miners often work in close proximity to electrical equipment and systems. Ensuring electrical safety is crucial to protect them from potential electrical hazards, including electric shocks, fires, and explosions.

+ Preventing Accidents: Electrical accidents can have catastrophic consequences in underground mines. Fire or explosion incidents can lead to injuries, loss of life, and extensive damage to mining infrastructure. Enhancing electrical safety helps minimize the risk of such accidents.

+ Compliance with Regulations: Adhering to national and international safety standards and regulations is essential. Failure to do so can result in legal repercussions and penalties for mine operators. Enhancing electrical safety ensures compliance with these standards.

+ Operational Continuity: Electrical failures can disrupt mining operations, leading to downtime, production losses, and increased costs. A robust electrical safety framework helps maintain operational continuity by reducing the likelihood of electrical failures.

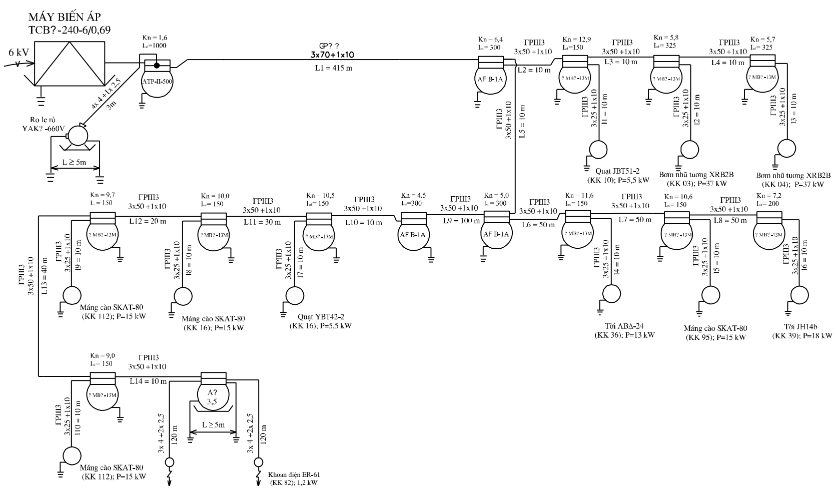

Figure 1. *660V grid in underground mines of VietNam [15], [33]*

+ Economic Viability: Mining is a significant contributor to Vietnam's economy. Ensuring electrical safety in underground mines is essential for sustainable growth. Reducing accidents and operational disruptions safeguards the industry's economic viability.

+ Technological Advancements: The mining industry is evolving with the integration of advanced technologies, such as automation and remote monitoring. These technologies rely heavily on electrical systems. Enhancing electrical safety is crucial to harness the benefits of these innovations while mitigating risks.

+ Environmental Protection: Electrical incidents can lead to environmental pollution and contamination. Leaks, fires, or explosions may release hazardous materials or cause ecological damage. Enhanced electrical safety measures help protect the environment surrounding the mining site.

+ Reputation and Investment: A commitment to electrical safety improves the reputation of mining companies and can attract investment. Investors are more likely to support operations that prioritize safety and sustainability.

+ Long-Term Sustainability: A focus on electrical safety contributes to the long-term sustainability of underground mining in Vietnam. By preventing accidents and ensuring reliable operations, the industry can thrive and continue to provide essential resources.

Because of the importance of electrical safety in mining industry [26-30], many researches [8-10], [22] proposed solutions for precaution or pre-assessment if the accident should sudden arises. Other one recommend equipment for fast detecting or eliminating the cause of accident [12-14], [16-20], [21-26]

In accordance with Vietnamese National safety regulations [11], [12], [15], [32], all metal frames of motors and electrical equipment must be connected to two grounding systems: one is an individual grounding rod, and the other is the centralized grounding system situated at the transformer substation. An illustration of these systems can be found in Figure 3.

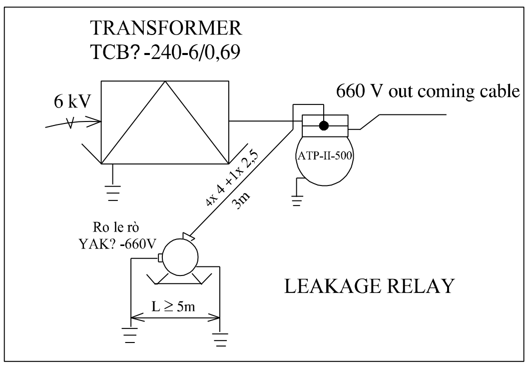

Figure 2. Leakage relay at transformer substation of underground mining grid in VietNam [15], [33]

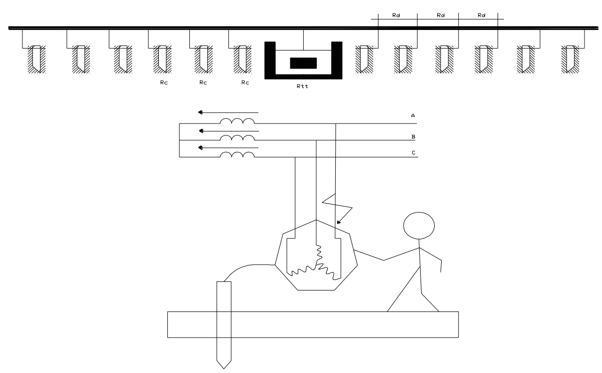

Figure 3. 660V grid in underground mines of VietNam [15], [33]

In this figure, by earthing the metal parts of uncovered accessories, the accidental leakage current could have easy path to close-circuited back to earthing relay, the excursion of current is presented in figure 4. As described in [15] and [32] the root-means-square (rms) of the current, hence the sensitivity of the relay depends on many internal factors of the grids including: the length of cables, the number of energy supplied equipment, rated voltage… By understanding those factors and their impact on leakage current could assist the mining technicians optimize the operation as well as the reliability of relay [13], [15], [23], [31]. A part from many above mentioned studies, two typical parameters of 660V grids in Vietnam coal mines are eliminated in calculation the earthing current. The main aim of the paper is to focus on the

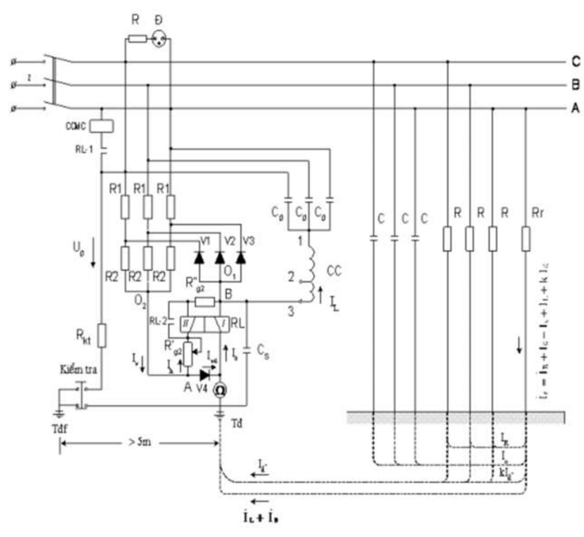

Figure 4. The expression of leakage current feeding back to leakage relay typed YAKИ

load ratio and various structure of 660V network to identify their impact on 660V leakage current, then propose solutions for improving the electrical safety.

2. BASIS THEORY OF LEAKAGE CURRENT CALCULATION IN 660V UNDERGROUND MINES

To analyze electrical safety, it is necessary to determine the current that flows through a person upon touching electrically conductive components of the grid. The magnitude of this current is calculated using the following equation (1) [31], [32], [33].

$$I_n = U_f g_n \sqrt{\frac{\left(3g + \frac{r_0}{r_0^2 + \omega^2 L^2}\right)^2 + \left(3\omega C - \frac{\omega L}{r_0^2 + \omega^2 L^2}\right)^2}{\left(3g + g_n + \frac{r_0}{r_0^2 + \omega^2 L^2}\right)^2 + \left(3\omega C - \frac{\omega L}{r_0^2 + \omega^2 L^2}\right)^2}} \tag{1}$$

Where g_n-body's admittance, $g_n = 1/R_{ng}$;

C-compensated capacitance;

L- inductance of compensation coil, the coil is mankind connected to neutral point of the grid;

When the capacitance element of the grid is partially compensated, the current value is calculated by equation (2), and when it is fully compensated, the current is determined using equation (3).

$$I_n = \frac{U_f}{R_n \cdot \sqrt{1 + \frac{R_{cd}(6R_n + R_{cd})}{9R_n^2(1 + \omega^2 C_{cd}^2 . R_{cd}^2)}}} \tag{2}$$

$$I_n = \frac{3U_f}{3R_n + R} \tag{3}$$

In equations (1), (2) and (3) the current running through the human being's body depends strongly on 2 factors:

+ C_{cd}-Capacitance elements of grid (which is proportional to the length of feeders and the numbers of apparatus connected to grid [32], [33];

+ R_{cd}-insulation resistance of grid..

Those quantities in previous researches are supposed to be independent with load ratio and structure of the grids. Hence, the next part of the paper, these factors will be the main aims for analysis to the rms of leakage current.

3. ANALYZING THE IMPACT OF LOAD RATIO AND GRIDS' STRUCTURES ON LEAKAGE CURRENT

3.1. Analyzing the impact of grids' structure on leakage current

According to the accounting data [32], [34] there are three kinds of grid structure in 660V underground mining grids: single routine, two branches and skeleton, the simulation diagrams of those structures are presented in figure 5, 6.

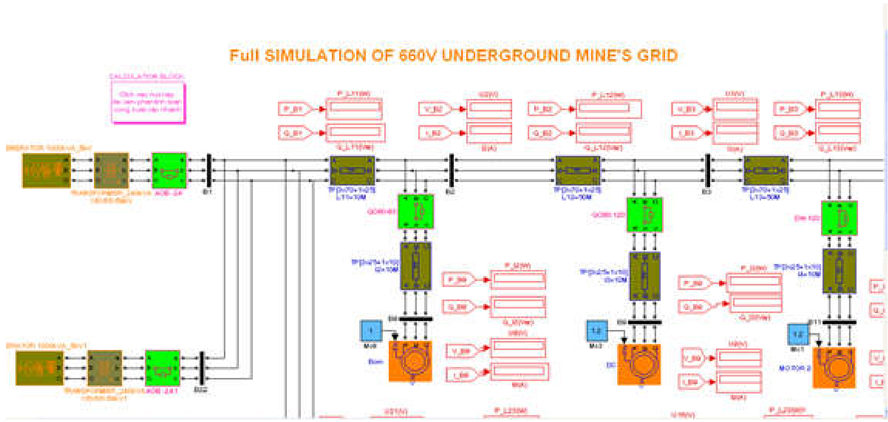

Figure 5. *The diagram of single routine grid*

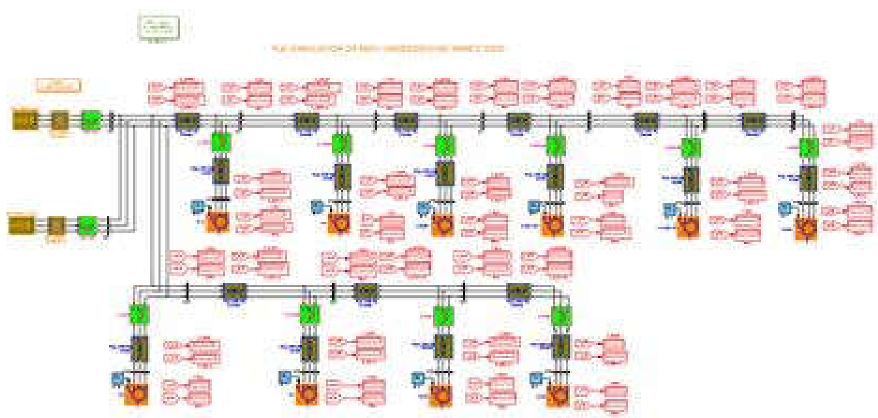

Figure 6. *The diagram of skeleton grid Implementing the simulation in MATLAB, the outcomes are shown in figure 7 and 8*

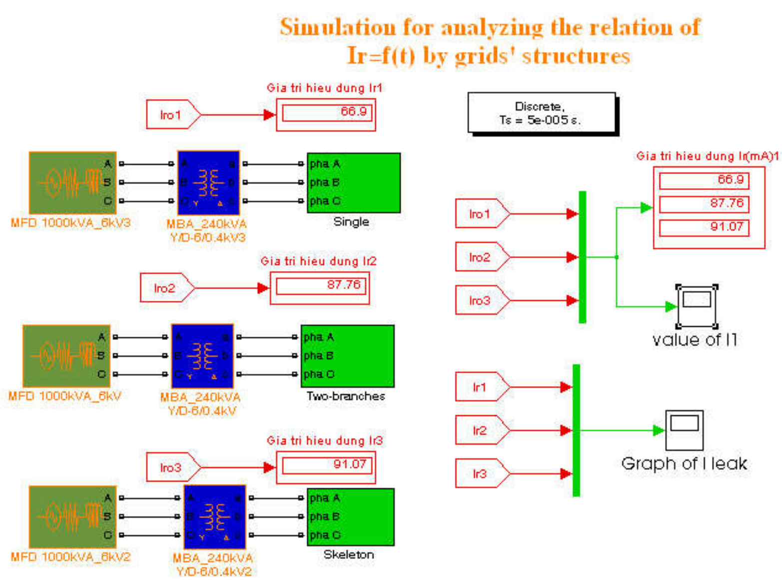

Figure 7. *The block diagram showing the calculation of leakage current I_r in various structure of grid*

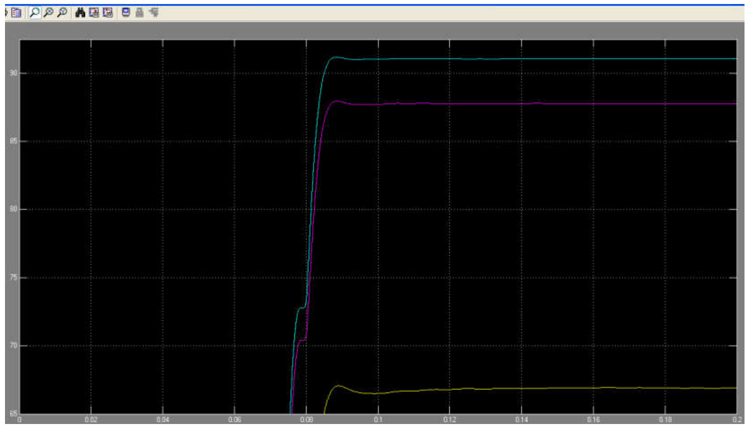

Figure 8. *The graph of $I_r = f(t)$ corresponding to various structure of grid*

The results show that with the same source but different grid's structure, the rms of leakage current has a significant bias (66.9 mA compare to 91.07mA).

3.2. Analyzing the impact of load ratio on leakage current

- Implementing in the same grid with parameters exhibited in

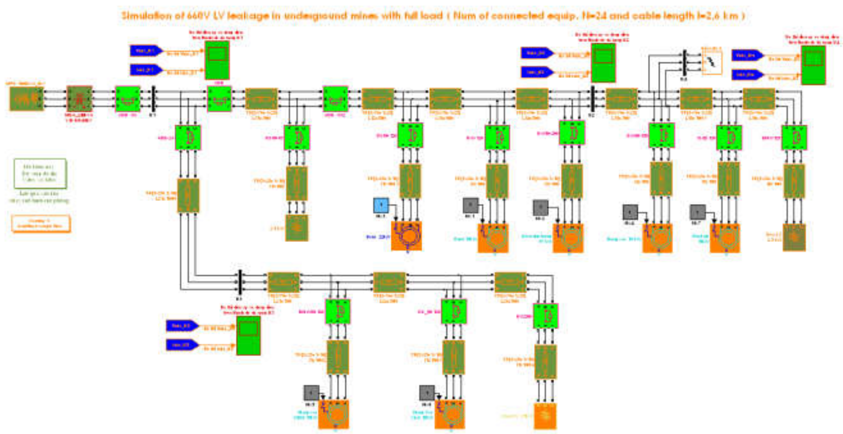

Figure 9. *The block diagram showing the calculation of leakage current I_r with load variation*

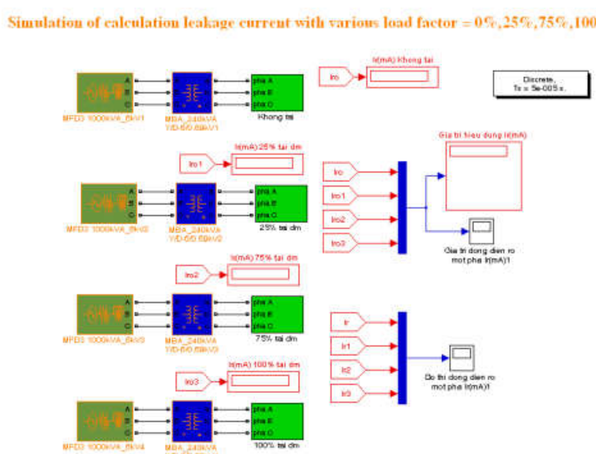

Figure 9. *The block diagram showing the calculation of leakage current I_r with load variation*

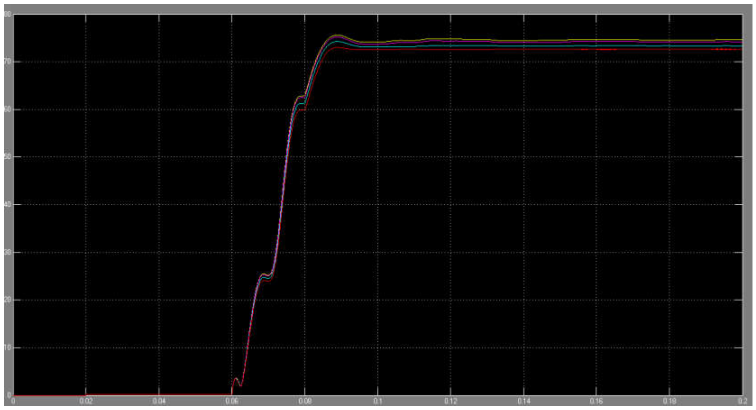

Figure 10. *The graph of I_r with load variation*

3.3. Other results from various underground mines

The simulations are implemented with some typical underground coal mines in QuangNinh of VietNam, the outputs are presented in table 1 to table 2:

Table 1: Results presenting the impact of Load on leakage current

Name	U_{nom} (V)	Structure	Ratio of Load/full load	Rms of leakage current (mA)
QuangHanh	660	Skeleton	20%	41,2
	660	Skeleton	50%	62
	660	Skeleton	70%	87,6
DuongHuy	660	Skeleton	20%	48,2
	660	Skeleton	50%	68
	380	Skeleton	50%	63,6
HaLam	660	Skeleton	20%	49,8
	660	Skeleton	50%	73,6
	660	Skeleton	70%	83,1
	660	Skeleton	95%	98,7
ThongNhat	660	Single-routine	20%	51,4
	660	Single-routine	50%	64
	660	Single-routine	70%	77,6

Table 2: Results presenting the impact of grid's structure on leakage current

Name of Coal mines	U_{nom} (V)	Structure	Ratio of Load/full load	Rms of leakage current (mA)
QuangHanh	660	Skeleton	70%	87,6
	660	Single-routine	70%	71
DuongHuy	660	Skeleton	50%	83,6
	380	Single-routine	50%	68
HaLam	660	Skeleton	50%	83,1
	660	Single-routine	70%	73,6

ThongNhat	660	Skeleton	70%	77,6
	660	Single-routine	70%	61,4

3.4. Conclusion

By utilizing the simulation in MATLAB, the paper investigated the impact of girds' structure and load ratio. The results deducted from the computing process show the following conclusion:

+ Corresponding to 3 typical structure of 660V underground mining grids, there are significant difference of leakage currents, the difference is nearly 50% and all of results are violate the allowance limit [11-13], therefore the manager should consider from designing stage for applying single routine diagram to reduce the rms of leakage current.

+ When the load is varied, the bias of I_r is about 15%, it is not so big, therefore the impact of load ratio could partly ignore in analyzing the electrical safety in underground mines.

+ In both cases, when no capacitance compensation is implemented, the rms of earthing current is violated the domestic and international allowance limit, hence there should be additional technical methods to enhance this unwanted fact.

REFERENCES

[1] NFPA 70E - *Standard for Electrical Safety in the Workplace* https://www.nfpa.org/-/media/Files/Code-or-topic-fact-sheets/70E2021FactSheet.ashx (accessed on 17th October 2023)

[2] IEC 60364-4-41 - *Electrical installations of buildings* - Part 4-41

[3] OSHA 29 CFR 1910 Subpart S – Electrical, USA.

[4] IEEE 1584 - IEEE *Guide for Performing Arc-Flash Hazard Calculations*

[5] IEEE 902 - IEEE *Guide for Maintenance, Operation, and Safety of Industrial and Commercial Power Systems* (Yellow Book)

[6] Richard B. Rubio, Electrical Safety - *A Practical Guide to OSHA and NFPA 70E*, Amazone publisher, 2018.

[7] Dennis K. Neitzel, *Electrical safety Update? OSHA 29 CFR1910.269 and NFPA 70E?-2015 Revisions*. IEEE Transactions on Industry Applications, 2016 http://dx.doi.org/10.1109/TIA.2016.2541098

[8] US department of Labor, *Electrical Safety Precautions Save Miners' lives* https://blog.dol.gov/2023/05/22/electrical-safety-precautions-save-miners-lives (accessed on 17th October 2023)

[9] Lixia Niu, Jin Zhoa and Jinhui Yang, *Risk Assessment of unsafe acts in coal mine gas explosion accidents based on HFACS-GE and Bayesian Networks*, Processes journal, February 2023-11(2), https://doi.org/10.3390/pr11020554

[10] Vlad Mihai Pasculescu, Dragos Pasculescu, Marius Simion Morar, *OHS risk assessment-a case study for underground coal mining electricians*, SWS Journal of Earth and Planetary Sciences, 2020, http://dx.doi.org/10.35603/eps2020/issue1.03

[11] Vietnam National regulation on safety Mining, QCVN 01:2011/BCT, 2011. http://www.kiemdinh.vn/upload/files/QCVN%2001-2011-BCT%20An%20toa%CC%80n%20trong%20khai%20tha%CC%81c%20than%20h%C3%A2%CC%80m%20lo%CC%80.pdf

[12] Coal Mining Safety and Health Regulation 2017, Part 4 *Electrical activities, equipment and installations*. https://www.legislation.qld.gov.au/view/pdf/asmade/sl-2017-0165

[13] *Safety Standards for Electrical Installations and Equipment in explosives facilities*, JSP 482 MOD Explosives Regulations, May 2016. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/529168/20160526-JSP_482_Edt4_1_Chapter_8.pdf

[14] Niculescu, T., Arad, V., Marcu, M., Arad, S., & Popescu, F.G. (2020). *Safety barrier of electrical equipment for environments with a potential explosion in underground coal mines*. Mining of Mineral Deposits, *14*(3), 78-86. https://doi.org/10.33271/mining14.03.078

[15] Le Xuan THANH, Ho Viet BUN, *A new approach on AI application for grounding resistor prediction in underground mines of VietNam*, Naukovyi Visnyk Natsionalnoho Hirnychoho Universytetu journal, Vol 5, 2022

[16] Zheng, L., & Liu, S. (2018*). A survey of remote monitoring and fault diagnosis for power equipment based on IoT technology*. IEEE Access, 6, 10491-10502

[17] Ustun, T. S., & Ince, N. F. (2019). *Remote sensing applications for electrical grid safety: A comprehensive review*. IEEE Access, 7, 47498-47513

[18] Dong, X., & Goebel, R. (2018). *Best practices in electrical safety management: A case study of a large industrial facility*. Journal of Loss Prevention in the Process Industries, 55, 202-211

[19] He, Y., & Liu, L. (2019). *Emerging technologies for electrical safety: A review*. Sustainable Energy Technologies and Assessments, 35, 14-22

[20] Chen, X., & Huang, J. (2018). *An overview of electrical safety regulations and standards worldwide. Safety Science*, 105, 19-27

[21] Yan, Y., & Chen, C. (2017). *Analysis of the effectiveness of electrical safety regulations: A case study of the construction industry*. Journal of Construction Engineering and Management, 143(12), 04017105

[22] Khan, F., & Abbasi, S. (2018). *Electrical safety risk assessment in industrial settings: A review. Process Safety and Environmental Protection*, 116, 255-266

[23] Al-Haddad, S. A., & Rahman, M. A. (2018). *Advanced technologies for electrical safety enhancement in smart grids: A review*. IEEE Transactions on Industrial Informatics, 14(3), 1228-1236

[24] Zhang, J., & Zhang, C. (2017). *Electrical safety enhancement through innovative sensor technologies: A review*. IEEE Sensors Journal, 17(18), 5775-5784

[25] Kecojevic, V., Komljenovic, D., & Groves, W. (2007). *Analysis of fatalities and injuries involving mining equipment*. Journal of Safety Research, 38(4), 461-470

[26] Shishvan, S. S., Ataei, M., & Oraee, K. (2007). Modeling risk and its application in the selection of a mining method for an ore deposit in Iran. *Journal of the Southern African Institute of Mining and Metallurgy*, 107(11), 759-766

[27] Zhang, J., & Jee, S. (2018). *Risk assessment and risk management of underground coal mines in China*. Journal of Cleaner Production, 176, 35-45

[28]Brnich, M. J., Veverka, A., Chekan, G., Howerton, D., Hill, T., & Janisko, S. J. (2018). *Analysis of surface and underground coal mine fires involving mobile equipment*. Safety Science, 110, 225-235

[29] The Minerals Council South Africa. (2019*). Guideline for the Compilation of a Mandatory Code of Practice for Risk Based Emergency Care on a Mine*

[30] International Commission on Radiological Protection. (2017). *Occupational Radiological Protection in the Mining and Processing of Raw Materials*. ICRP Publication 132

[31] Xiaoning Qi, Sam C.Lo, Alex Gyure, Yansheng Luo, Mahmoud Shahram, Kishore Singhal and Don B.MacMilen, 2006, *Efficient subthreshold leakage current optimization*, IEEE circuits and devices magazine, September 2006

[32] Kim Ngoc Linh, 2006, "*Research the suitable leakage current protection utilized for Quang Ninh low voltage underground mines*", Unpublished Doctor dissertation, Hanoi University of Ming and Geology

[33] Le Xuan THANH, Ho Viet BUN, *Analyzing and identifying the limits of 660V grid parameters to ensure electrical safety in underground coal mines*, Naukovyi Visnyk Natsionalnoho Hirnychoho Universytetu journal, Vol 6, 2021 https://doi.org/10.33271/nvngu/2021-6/101

[34] Nguyen Anh Nghia, Nguyen Hanh Tien, *Electric power supply for underground mining* book for master of Electrical Engineering, Publication of Hanoi University of Mining and Geology, 2008.