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Electric Vehicles in Mining for the Aspect of Operational Safety

Abstract. *Battery electric vehicles are becoming an opportunity for sustainable development in mining. There are several advantages of electric vehicles in mining, primarily related to improving the safety of miners' working conditions. It is significant for mining workers that electric vehicles are not a significant additional source of heat, reduce the emission of exhaust gases in the environment of their use, and are characterized by very little or no harmful gases released into the atmosphere. Currently, the mining industry is developing several initiatives for sustainable development, bringing together mining companies, suppliers and research institutions to accelerate technology development and effectively implement BEVs (battery electric vehicles) in the mining industry as soon as possible. These activities are accepted by miners, although, like any modern technology, they raise legitimate concerns and become the beginning of reflection on the safety standards for using electric vehicles that should accompany their development. This article reviews electric vehicles in mining works. Concerns for the development of these technologies have been identified. Particular attention was paid to the concerns about the operational safety of electric vehicles in the mining environment.*

Streszczenie. *Pojazdy akumulatorowe stają się szansą na zrównoważony rozwój w górnictwie. Zalet pojazdów elektrycznych w górnictwie jest kilka, przede wszystkim związanych z poprawą bezpieczeństwa warunków pracy górników. Dla górników istotne jest, że pojazdy elektryczne nie są znaczącym dodatkowym źródłem ciepła, redukują emisję spalin w środowisku ich użytkowania oraz charakteryzują się bardzo małą emisją szkodliwych gazów lub całkowitym ich brakiem. Obecnie przemysł wydobywczy rozwija kilka inicjatyw na rzecz zrównoważonego rozwoju, skupiając firmy górnicze, dostawców i instytucje badawcze w celu przyspieszenia rozwoju technologii i jak najszybszego wdrożenia pojazdów typu BEV (battery electric vehicles) w górnictwie. Działania te są akceptowane przez górników, choć jak każda nowoczesna technologia budzą uzasadnione obawy i stają się początkiem refleksji nad normami bezpieczeństwa użytkowania pojazdów elektrycznych, które powinny towarzyszyć ich rozwojowi. W artykule przedstawiono przegląd pojazdów elektrycznych w pracach górniczych. Zidentyfikowano obawy dotyczące rozwoju tych technologii. Szczególną uwagę zwrócono na obawy dotyczące bezpieczeństwa eksploatacji pojazdów elektrycznych w środowisku górniczym. (**Pojazdy elektryczne w górnictwie w aspekcie bezpieczeństwa ich użytkowania)***

Keywords: electric vehicles, operational safety, mining.
Słowa kluczowe: pojazdy elektryczne, bezpieczeństwo, górnictwo.

Introduction

Access to ore in mined mines becomes complex over time. As a result of the exploration, deposits are located more profoundly, and their quality is deteriorating. That brings in the need to employ more and more mining vehicles, which account for an average of 50 per cent of the mine's total direct emissions [1]. However, traditional diesel vehicles (DV), commonly used in mines, have several disadvantages. [2] indicates that diesel vehicles in mining have low efficiency (35%), low overload capacity, high maintenance cost, require skilled mechanics for maintenance, are noisy (~105 dB), can cause fog formation, and generate high heat. Moreover, in the aspect of development, they are difficult for data gathering, remote monitoring and building autonomously. Also, there is an impediment in fuel transportation for DV in deep mines.

As a result of numbered issues with DV, some sustainability initiatives within the industry, mining companies, vendors and research institutions to support innovation and haste the adoption of new equipment, including BEVs, have been started. For example, in European Union, a project was financed as part of the activities of the Horizon 2020 program. The project's name was SIMS from Sustainable Intelligent Mining Systems. The project was carried out by a consortium of mining companies, equipment and system suppliers to top-class universities. However, this initiative had a few goals [3]:

- automated planning and reporting of mining progress through ground control to improve event planning (a digital twin), improve results and improve safety in production,
- battery electric vehicles implementation and testing in the operating mines,
- development of training modules for operators and mine workers and educational modules for students and the general public,
- communication and positioning – development and testing in operating mines.

Enterprises involved in the project include KGHM Poland, K + S Germany, Boliden Sweden, Lulea Sweden, Agnico Eagle Finland, LKAB Sweden, ABB, Epiroc, Ericsson and Mobilaris.

Another example of a sustainable mining initiative is International Council on Mining and Metals (ICMM), a global leadership organization for sustainable development. It has 37 association members and 26 Company members (currently). As the official website introduction says [2]: the primary goal of the organization's Innovation for Cleaner, Safer Vehicles (ICSV) initiative is to enable its members the meeting in a non-competitive space. Such an environment can create conditions for the world's largest original equipment manufacturers (OEMs) to accelerate the development of a new generation of mining vehicles and improve existing ones. In addition, the program focuses on motivating and encouraging activities directed at project participants to encourage them to find the advantages of the electrification of mining vehicles [4].

The result of such initiatives is electric vehicles being gradually introduced into the mines. Their design and operating conditions depend on the intended use and the mine (open-cast, underground) in which they are used. Notwithstanding the many advantages electric vehicles carry in mines, their emergence creates new risks and concerns for use. The previous pilot projects and the first attempts to use this type of vehicle have allowed identifying potential problems that may arise from introducing electric vehicles to the mine.

Electric Vehicles in mining

Undoubtedly, regardless of the technology used, electric vehicles have numerous advantages over diesel vehicles traditionally used in mining [5]:

- higher energy efficiency (about 90%);
- constant torque (including high torque at low speeds),

- quick response to the load and better overload capacity,
- no exhaust fumes and therefore no mine air pollution and no fog formation,
- generate only a third of the heat emitted by a diesel having the same power
- hourly electric energy cost lower than hourly fuel cost for diesel,
- less maintenance required,
- low noise and vibration level.

The dynamic development and increased interest in battery electric vehicles in mining have been visible for the last ten years. However, other solutions are available for a much more extended period. Nonetheless, vehicle manufacturers already offer a wide range of electric vehicles for various mining activities. As shown in Table 1, mines can choose from: electric rope shovels, Electric Load-Haul-Dump (eLHD) trucks, Electric Haul Trucks, Electric Drills, Electric Service Vehicles, electric crushers, Electric scoops, boomer and smaller trucks, Electric locomotives, Battery-electric explosives charger, Rock bolting rigs and conveyors. However, they differ in the used technology of batteries and charging systems. In addition, design and operational considerations vary for different equipment types. For example, tethered equipment typically requires accommodations for the cable, while trucks might focus more on regenerative braking. [6]

First can be mentioned electric vehicles used in 1975 like electric rope shovels, powered by the power grid. However, the need to power the cable from the mains may cause damage to the cable, electric shock hazards, and vehicle downtime. Moreover, the vehicle's operating range is limited due to the cable length. Therefore, this technical it is impractical for trucks, so not many vehicles have been commercialized [5]. Since these vehicles do not need refuelling, what makes them time efficient.

Another solution, used in mines for over a hundred years, represented by, e.g. Electric Haul Trucks by ABB and Caterpillar (see Tab.1), is trolley-powered equipment. This technology powers electric rail or trackless vehicles from an overhead cable. It is impractical but creates an attractive alternative for mine trucks, particularly those working on long ramps (up to a few kilometres) [5]. The modernization and development of this technology is BluVein. The system is based on a slotted power rail set down into a public highway. The conductors are not exposed, so it is safe for people, animals and vehicles to pass over it. Electric trucks drive over the rail at 80 or 100 kph, automatically deploying an arm connecting to the rail. The truck can then draw electricity to power itself and charge its battery for later use [7]. The benefits of this solution are eliminating battery replacement, removing downtime for charging, or the possibility of using smaller batteries [8]. However, attention-grabbing, the technology is under development and will be installed in 2022 for a six-month co-trial with the various mines.

Through the current advances in battery technology, since 2016 become possible to manufacture reliable battery electric vehicles (BEVs). These can be used in all mining methods. Also, those requiring regular movement between working levels, such as sublevel stop, cut and fill, small/medium-scale sublevel caving, and room and pillar, can operate on average mine roads. [9] Generally, battery electric vehicles, due to the charging technology, can be divided into [6]:

- On-Board Charging,
- Off-Board Charging of On-Board Batteries,
- Off-Board Charging of Off-Board Batteries (Battery Swapping),
- Hybrid Charging Method,
- Off-Board Proprietary Chargers,
- Alternative Charging Systems and Equipment Types (Overhead Catenary Systems Or Trolley Assist and Charge-While-Operating (Tethered) Electric Equipment

Table 1. Electrically/battery-powered machinery (based on [1], changed with updates)

Electric rope shovels	Electrically-powered from grid
	Used in surface mining and for loading in-pit crusher-conveyor systems and haul trucks
	DC type available by Komatsu, Caterpillar and IZ-KARTEX, Liebherr, Hitachi, Finning Cat
Electric Load-Haul-Dump (eLHD) trucks	Commonly used underground battery vehicles.
	By GE, Caterpillar (with fast on-board charging), Epiroc
Electric Haul Trucks	Employed for ore transportation typically in difficult geological conditions, under stringent safety issues, and for large production
	The emerging market includes several companies: Caterpillar, Volvo Group, John Deere, CNH Industrial, Komatsu and Epiroc.
	ABB and CAT: trolley-based systems
Electric Drills	An all-electric drill uses AC electric motor driving a hydraulic circuit which moves hydraulic percussive rotary hammers.
	An electric vehicle can transport the drill from one location to another.
	By Sandvik and IZ-KARTEX, Epiroc
Electric Service Vehicles	Utility EVs used at an underground gold mine by Bortana-EV
electric crashers	By Volvo Construction Equipment in partnership with Skanska Sweden
Electric scoops, boomer and smaller trucks	By Epiroc (Atlas Copco)
Electric locomotives	Driver assist and unmanned types
	Anglo American Platinum
Battery-electric explosives charger	By Normet
Rock bolting rig	By Sandwig
Battery-Powered LED Light Tower	By Atlas Copco
Conveyors	Multiple companies,
	Distributed/central and induction

According to research studies [10], BEV makes it possible to reduce the downtime of diesel vehicles despite the need for loading. Also, modern solutions like those used in the Rock bolting rig by Sandwig enable battery charging during, e.g. drilling.[11]

Problems identified for EV development in mines

Problems defined by literature can be generally divided into four main groups: safety, operational, infrastructure, and global issues. From the user's point of view, operational

issues are the most disturbing everyday work. Those make their work inconvenient and inefficient. For example, miners point to the necessity of battery charging as their primary concern with BEV [9]. Also, mining staff for the safe operation of BEV needs additional training and, in some cases, changes in competencies [12]. Skills with growing demand include system evaluation and analysis, mathematics, active listening, instructing, data analysis, data and digital literacy, and judgment and decision-making [12]. Skills with decreasing demand include vehicle operations, materials extraction, operations and control, equipment maintenance and blast-hole drilling [12].

An inconvenience in the extensive use of electric vehicles is the need to adapt the infrastructure. The unique infrastructure like a charging room or a system for battery charging is indispensable for battery charging [4]. Space and infrastructure are needed to test, maintain, discharge, charge, and store batteries [6]. In addition, chargers must meet requirements for operating under the ground, with specific temperature and humidity, and the need for power supply from the electrical system available in the mine. It is necessary to avoid temperatures above 30 degrees [13] and under 0 degrees [14], the same as frequent fast DC high power charging mode [15]. Also, according to [16], battery modules' voltage should be tested, and used modules should be replaced to ensure long-term and reliable operation. . In systems like BluVein, the whole infrastructure of slotted rails is needed. Therefore, introducing electric vehicles to mines is easier in the case of newly created mines, including electric vehicles already at the design stage.

Of course, BEVs also bring general concerns like materials like lithium, cobalt, and copper accessibility to manufacturing batteries in the future. Another problem is battery utilization. Those problems might become significant with BEV popularisation.

However, a thing of the most significant concern is electrical safety. Safety issues may be connected with a few safety matters. First can be mentioned situations during normal operational conditions. Mining workers designated [9] possible accidents which may occur because of too quiet work of BEV. Miners used to louder conditions may be victims of car hits and similar accidents. They may not be aware of Bevs' presence in their vicinity. Also, the risk of electrocution raises concerns. People traditionally using diesel mining equipment are often not trained to work with electric vehicles. They are afraid of electrocution, especially periodically performed maintenance operations.

Most safety concerns are connected to batteries. While the charging process. During the charging process, the battery may overcharge, which may damage the battery. Workers are concerned about the risk of electric shock if the battery needs to be replaced. Research [16,17] shows that both, the environmental conditions and the method of charging, are significant for the functioning of the battery. Also, battery systems under the ground are exposed to the traditional hazards of such systems under normal operating conditions. These are identified by [18] as after-accident ignition, electric shock due to the energy remaining in the batteries, and re-ignition due to energy not being discharged. The problem is that those situations under the ground are even more dangerous and hard to handle.

A significant impact on the safety of the charging process also has communication. Regarding safety, communication protocols are exposed to various information security threats, including natural elements (natural disasters, poor communication locations, deterioration of equipment performance) and human elements (destruction, fraud, theft, human lack of skills, malicious network attacks). In the event of communication errors, the electric vehicle may not be charged. Also, the charging process may be interrupted (which affects the efficiency of operation) or overcharged, which may even result in the self-ignition or explosion of electric vehicles and charging devices. [19]

Requirements for BEV users in mining

Due to the novelty of the topic and the lack of widespread use of electric vehicles in mining, unfortunately, there are no clear guidelines regarding the requirements that this equipment should meet. Therefore, it is one of the barriers to the widespread use of EVs in mining. However, the requirements for vehicles should result from the hazards that may occur, and these are difficult to define only under simulation conditions. However, so far, there are only recommendations that should be met by electrical equipment.

Such recommendation is a document "Recommended Practices for Battery Electric Vehicles in Underground Mining" [6] issued by The Global Mining Guidelines Group (GMG). GMG is a network of representatives from mining companies, original equipment manufacturers (OEMs), original technology manufacturers (OTMs), research organizations and academics, consultants, regulators, and industry associations worldwide who collaborate to face the new mining industry challenges. The document defines, among other things, what threats can potentially be generated by the technologies used and what standards theoretically they should meet. Decisions on the admittance of products for use in mining plants in Poland, based on [20], remain in force of the mining plant decision-makers. Decisions regarding the operation of the mining plant should be based on the existing regulations and include natural hazards occurring in mining plants. Due to the lack of applicable standards, making such decisions may be limited and contribute to a slowdown in electrification in the Polish mining industry. The conclusions from the experiences of other mines in the world published, e.g. by GMG, might be helpful for the decision-makers.[6]

Most common safety issues may be generally divided into energy storage - batteries connected ones and those about charging systems. The charger must be well-matched with the energy storage type and chemistry used at the mine, respected for the applicable charging rate (slow or fast), and compatible with different conditions. The charging system enclosure/shell should also have the appropriate environmental protection rating (IP) according to the installation location. Additionally, the system needs to be monitored, so there are no open plugs. Finally, the charger installation should comply with local codes and undergo any necessary approvals or inspections.[6] Document concerning electric vehicles in Poland is [21]. However, it is not applicable because it defines charging stations as an element of the road public transport recharging infrastructure. Also, [22] does not apply to handling electrical equipment in mining, as it refers to the provisions of [20].

Because BEV batteries require frequent charging, exposure to potential hazards often occurs when personnel connect, operate, and disconnect the charging system. Currently, in repairing electric vehicles, the employee must have SEP qualifications up to 1kV. Due to the lack of regulatory requirements for using such vehicles in mining, similar requirements should be expected. Of course, the rights do not guarantee knowledge about handling batteries and electric vehicles with such a specific structure.

Therefore, one should expect the necessity to undergo training to operate the device's battery during its regular operation. It remains open questions. Who should conduct such training? Should it end with obtaining the appropriate certificate and which employees should be trained - replacing/charging the battery or all vehicle users or working in its vicinity? Due to [20], decisions must be considered within a given mining plant.

Recommendations

Before implementing electric vehicles, the risk assessment should be considered [23]:

- financial risks (e.g., increased infrastructure capital expense, early battery replacement)
- production risks (e.g., discharged vehicle recovery, production rate impact)
- health and safety risks (e.g., fire/explosion, electric shock, arcing fault)
- environmental risks (e.g., worn battery skulls toxic to the environment)

It is important to know why and where BEV will be needed, what is required and what type of equipment is necessary, and who is or should be trained to operate, maintain service and implement emergency procedures. [23]

Protection of equipment and installation should meet appropriate standards responding to the operational conditions (temperature, humidity and others). Excess dust, corrosion, condensation, water or other liquids should be eliminated to reduce the risk of accidents. Behalf of safe working conditions should be specified, required and applied proper maintenance and proper tools (Insulated tools). For the safety of users, battery training should be required. It is required to specify who should be responsible for the replacement of the battery, what conditions should be ensured so that such replacement is also safe underground, what means of protection should be provided to such a person, and what the procedure for admitting to work should be. This task is not easy because technology is still evolving. Training should focus on different user groups, such as Electricians, Service mechanics, and mechanical/electrical specialists. A training checklist for BEV mining vehicles and mining charging systems should also be developed for specific equipment. [23]

Conclusions

At the moment of writing this article, there are no obligatory recommendations for electric vehicle use in mining. The applicable documents concern the general principles of using electric networks, using electric vehicles, and admission to work with voltage. However, the conditions in mines require a risk assessment each time when working with a specific electric vehicle, determination of potential risks and rules for handling the device to avoid electric shock. It is crucial in traditional mines, the existing infrastructure of which is not adapted to using electric vehicles. Nevertheless, as indicated in the literature, despite the potential threats, electric vehicles in mining are its future and an opportunity for sustainable development.

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