e-ISSN 2719-3306 Mining Machines, 2024, Vol. 42 Issue 3, pp. 232-239

https://doi.org/10.32056/KOMAG2024.3.6.

Solid gravity energy storage in mine shafts – feasibility and functionality

Received: 29.08.2024

Accepted: 01.10.2024

Published online: 02.10.2024

Jacek KORSKI *

Author's affiliations and addresses:

KOMAG Institute of Mining Technology

Pszczyńska 37

44-101 Gliwice, Poland

*** Correspondence:**

e-mail: jkorski@komag.eu.

Abstract:

Power and Energy storaging is bacoming as one of contemporary the biggest chalenges. Main reason is development of renewable Energy sources and irregular production cycle. In article is described typology of energy and power storaging solutions and solid gravity energy storage (SGES) place in this typology with briefly description of gravity storages idea. As an industrial proces SGES are analyzed theoretical and practical SGES feasibility. Constraints and functionality of SGES is a background for SGES feasibility analysis in main areas of feasibility (technical, legal, economic and operational). Because expectations for SGES are not definied in article was done analysis for two ways – for existing shaft with equipment and for expected SGES capacity. Results of analysis are presented as final conclusions.

Keywords: energy storaging, solid gravity energy storaging, shaft as a storage, gravity storaging

Publisher: **KOMAG Institute of Mining Technology, Poland**

1. Introduction

Need for energy storage appeared in the 20th century with the popularization of using the electricity and with growing demand for it. Energy storage means capturing energy produced at a given moment and storing it for later use.

However, only in recent years, due to the growing ecological awareness and the related development of renewable energy sources (RES), there has been a sharp increase in interest in energy storage. Importance of energy storage is indicated by the UN 2030 Agenda for Sustainable Development, which includes affordable and clean energy as the seventh of the 17 Sustainable Development Goals [1].

Emergence of renewable electricity sources in the form of photovoltaic cells and wind generators has revealed a dissonance between the energy generation characteristics of these sources and the energy demand. This results in the loss of electricity already produced and insufficient use of the investment outlays. The idea of storing already generated energy in energy storage facilities has emerged. The idea of storing electrical energy was already known, but as systems stabilizing electrical systems (e.g. in cars with spark ignition combustion engines, now developed into cars with hybrid drives). Pumped-storage hydroelectric power plants have been built in large power systems for many years, the task of which is to stabilize such a system by storing excess energy production and releasing it when there is a shortage of energy in the system.

Many installations, not only industrial ones, are highly sensitive to power failures. In the case of smaller installations, electric generators powered by diesel engines have been successfully used for many years, often to protect only the most sensitive systems to ensure their continuity of operation;

Electricity storage in electric batteries (e.g. cars) has been used for many years as equalizing power supply (short-term) or alternative power supply (e.g. submarines).

Originally, all forms of energy storage (especially pumped-storage power plants) were used as compensation systems to protect industrial installations against power failures in power grids lasting at most a few hours. In this way, the most sensitive installations were protected [2, 3].

Nowadays, among the many possibilities of storing energy and/or power, there are also installations using potential energy, i.e. the phenomenon of gravity, including energy storage facilities using the water gravity in deep mine shafts. This article is devoted to the analysis of the last one.

2. Typology of energy or power storages in the light of current ideas

In Fig.1 current typology of energy storage developed in China is presented [4].

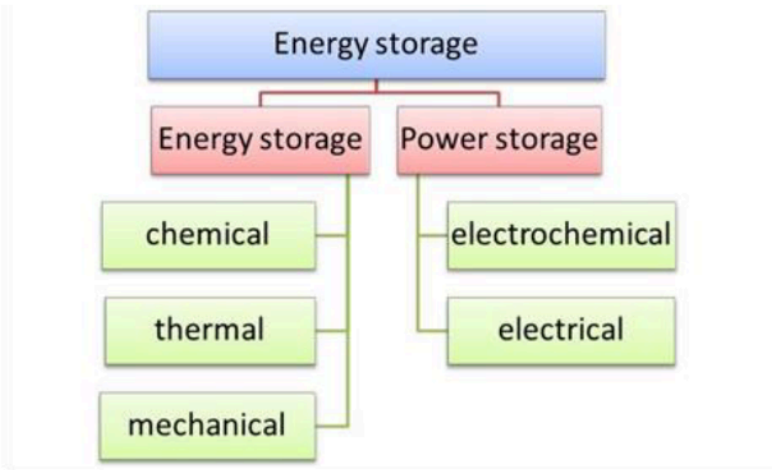

Fig. 1. General typology of energy storage [4]

Due to the thematic scope, energy storage systems using mechanical energy require a more detailed classification, which is shown in Fig. 2.

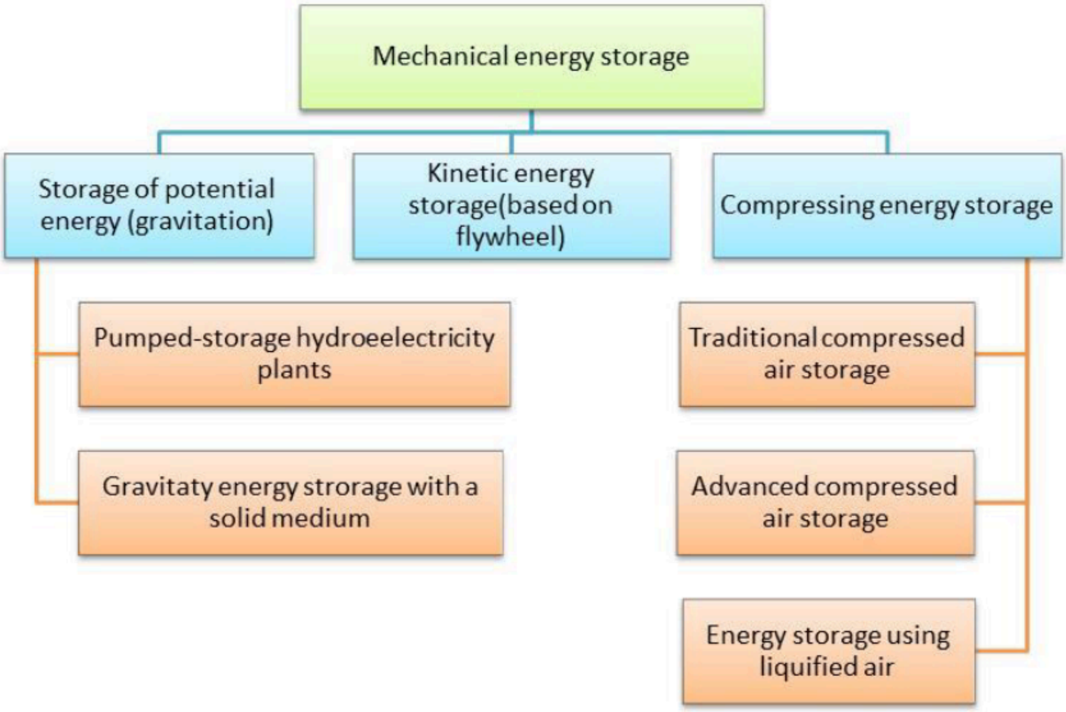

Fig. 2. Typology mechanical energy storage [4]

Pumped-storage hydroelectricity power plants have been built in large power systems for many years, the task of which is to stabilize such a system by storing excess energy and releasing it when there is a shortage of energy in the system. However, this solution has a significant drawback in the form of a high necessary difference in levels for the lower and upper water reservoirs and significant space requirements to obtain a enough capacity to store energy. Pumped-storage hydropower plants currently existing in Poland have an energy storage capacity of approximately 8 GWh, and the possibility of increasing this capacity is estimated to be several times greater at best. After lignite mining in the Turów open-pit mine ended, it is suggested to build a pumped-storage power plant in about 30 years with a capacity of 2,300 MW and a storage capacity of up to 160 GWh, which is relatively small [5]. Since the 1960s, the idea of using the liquidated underground mines as pumped-storage power plants, i.e. energy storage, still returns, but it has not been widespread so far.

Since around 2015, gravity storage of electricity has been replaced more and more often. A gravity storage is a type of electrical storage device that stores the energy accumulated in an object resulting from the change in height increasing its potential energy. Gravity storage works by using excess energy from the grid to lift mass to increase potential energy, which is then dropped down to convert the potential energy into electrical energy through an electric generator [5]. Many technology demonstrators were created in a form of towers with weights lifted in various systems.

It was only in 2023 that the first commercial surface gravity energy storage facility was launched in China (Fig. 3). The surface gravitational energy storage facility launched in the city of Rudong in China's Jiangsu province has a capacity of 100 MWh with a power of 25 MW. The general idea of this storehouse is to locate multiple loads next to each other in one building. Storing energy means lifting these weights, and releasing energy means lowering them. This ensures continuous operation of the storehouse compared to a single weight one and extends time of energy release [6].

Fig. 3. Energy storage system in, China under construction [*Image: Energy Vault, Business Wire*]

In 2017, the concept of using the mine shafts for energy storage was presented. The main argument for this solution is the significant depth of many shafts - greater than height of the structures on surface. In the case of liquidated underground mines, it is possible to use part of the remaining mine infrastructure, including hoisting machines (shaft hoist system) and the mine's power system. The social aspect of such an idea is also pointed out, in the form of preserving a certain number of jobs for people whose competences are difficult to use in other professions. For this reason, various concepts of underground gravity energy storage in mine shafts have been presented in recent years. Polish underground coal mining industry, whose mines had over 130 shafts at the end of 2023, according to some opinions, could become a potential energy storage complex. However, it should be noted that to date, no gravity energy storage in a mine shaft has been launched anywhere, not even in the form of an underground demonstrator. Various technical concepts of energy storage in mine shafts are presented, including those based on the idea of lowering and lifting large homogeneous masses or large groups of smaller weights or containers (with water or solid bulk materials).

3. Constraints, feasibility and functionality of solid gravity storage in abandoned mine shaft

For each technical solution, there are constrains resulting from various conditions, which translate into real constrains that determine the practical feasibility of the solution. The ideas for gravity energy storage in mine shafts presented in [2, 3, 4, 7, 8] do not analyse the environment, surroundings and constrains for the energy storage process, which in practice may translate into the feasibility of implementing the project. The existing constrains are, in practice, a consequence of environment in which the project is implemented by its close surroundings, which impose significant constrains (Fig. 4).

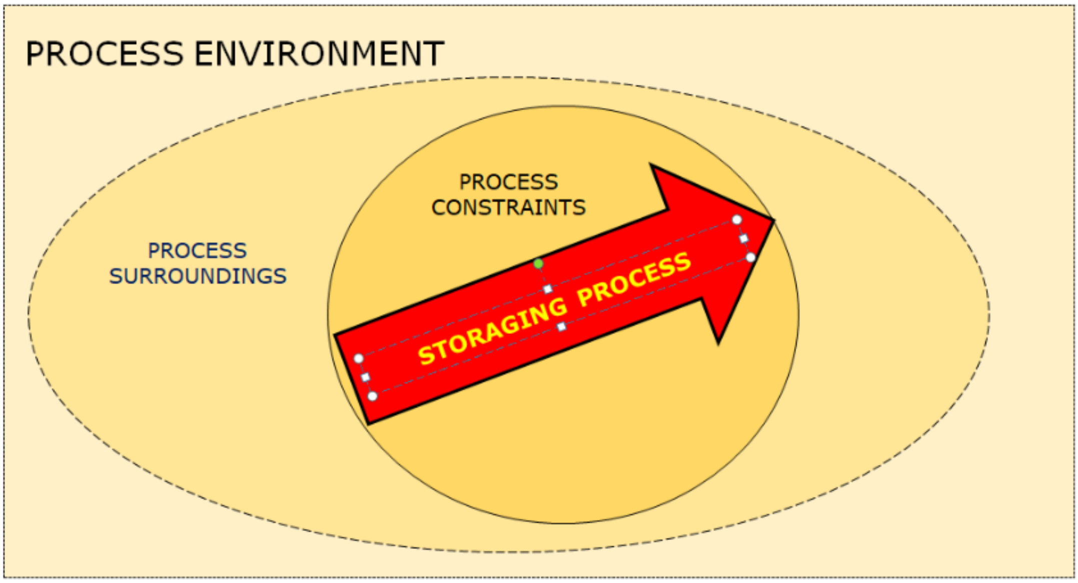

Fig. 4. Environment surroundings and constraints for the technical process [source: Author's]

Taking into account constraints in the designing process is necessary because it determines the possibility of implementing the planned project, i.e. in this case, a gravity energy storage facility in an underground mine shaft. It is indicated [8] that there are two levels of feasibility:

- Theoretical (dispositional) feasibility means that the intended project is consistent with the laws of nature (e.g. the laws of physics, mechanics, thermodynamics, etc.).
- Practical (situational) feasibility means that the intended project (object, process) can be implemented in specific conditions (including place and time).

The practical project feasibility, which should be separated from theoretical feasibility (Fig. 5), is an important issue.

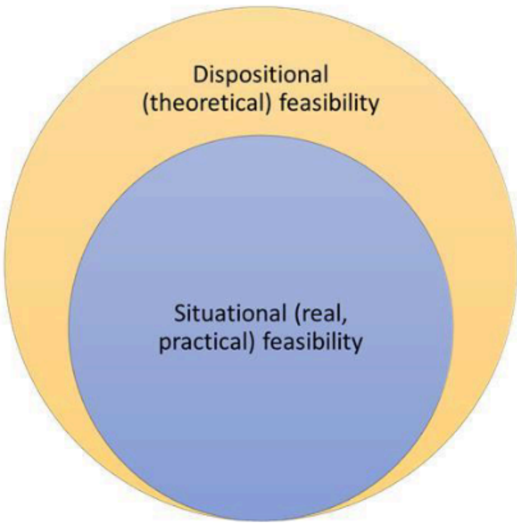

Fig. 5. Theoretical and practical feasibility [9]

Undertaking projects that are practically (situationally) impossible does not lead to achieving the intended goal, but generates costs and losses.

The basic areas of assessing the feasibility of a project involving the creation of a gravity energy storage facility are shown in Fig. 6:

- **Technical feasibility**. This is an assessment that focuses on the technical resources available to implement the project. It should be noted that in practice, resources in the sense of the socio-technical system should be considered, i.e. not only material resources, but also available human resources in the organization. Its task is to determine whether technical resources match the team's capabilities and whether employees are able to transform ideas into functional systems. Technical feasibility also includes the assessment of hardware or software.
- **Economic feasibility.** Economic feasibility assessment includes an analysis of the costs and benefits that the project may bring.
- **Legal enforceability.** This research assesses whether any aspect of the proposed design may conflict with legal requirements.
- **Operational feasibility.** The assessment involves conducting an analysis to determine whether the organization's needs will be met by implementing this project. This is an important aspect focusing on the utility or functionality of the project, which should be clearly defined
- There is another aspect to the feasibility assessment:
- **Feasibility planning.** This is the last and most important stage - the project could fail if it is not completed within the stipulated time. When planning feasibility, the organization's task is to critically estimate how long it will take to complete the project.

Fig. 6. Main aspects of assessing the project practical feasibility [Author's]

From the point of view of the purpose of building and operating an underground gravity energy storage facility, a very important aspect is the usefulness/functionality of such a system as an element of technical feasibility. The key parameters here are electrical power and the amount of stored energy, which together determine the time of energy release by the storage facility. The complexity of the system and the simplicity of its use and maintenance are also important. A mine shaft is an element of a very complex technical system, the elements of which normally serve to achieve the basic goal of mineral extraction and related processes [10]. Therefore, after the end of mining, it may be necessary to preserve not only the shaft intended for gravity energy storage, but also a larger number of facilities and installations ensuring the reliable operation of the storage facility over the expected time horizon (e.g. 25 years). The need to maintain a more complex technical system may affect the available time of warehouse operation [11].

Another issue is the scalability of the technical solution understood as the possibility of enlarging (increasing the scale of operation) the system or project [12, 13]. They are not clearly defined.

4. Practical feasibility of the gravity energy storage in mine shafts

To assess the practical aspect of a gravity energy storage facility, certain functional assumptions should be made for such an energy storage facility such as energy capacity, maximum power consumed and fed back to the network. The expected life of the storage facility is at least 25 years, and the operating time with energy release is up to 4 hours (as an example of the previously described surface gravitational energy storage in Riugong). Similarly, the capacity can be assumed to be 100 MWh and the electrical power to be 25 MW. The simplest idea assumes direct use of a shaft with an existing hoist shaft and the use of a hoisting machine in the system to generate energy when lowering the load. Assuming a shaft with a permissible weight of the cage/skip, e.g. 50 Mg, a depth (actually a free path) of 750 m and a maximum travel speed (nominal) of e.g. 10 m/s, theoretically we can store in it 1MWh of energy, which, after 4 hours of operation, would enable the generation of an average power of approx. 0.278 kW. Assuming the load moves at the hoist nominal speed (excluding acceleration and braking), the energy generation time did not exceed 75 seconds with a power output of approximately 48.1 kW. Assuming the speed of movement of the weight when lowering (energy generation) at a speed of 0.1 m/s, the travel time would be 7500 s, and the generated continuous power would be approximately 0.481 kW, which is probably lower than the energy demand of the storage facility. It is worth noting that the battery energy storage, e.g. Mereus ESS - type 1, with a capacity of 1.43 MWh, weighs 28 Mg and has dimensions of 12.2x2.45x4.1 m [14]

For the same shaft (load travel distance 750 m), the necessary weight of the load was calculated, to generate energy of 25 MWh it would require using the load or loads of a total weight of approx. 1248 Mg (what in the case of steel means a volume of approx. 158-166.4 m^3). In such a variant, it would not be possible to use the shaft hoist installation (hoisting machine, tower, ropes), and in a shaft with typical diameter, e.g. 7.5 m, the total length of the steel weight would be 3.6-3,8 m, with use of the shaft full cross-section, which would exclude maintaining any necessary installations in the shaft (pipes, cables, sensors). The proposed [7] division of the load into smaller load units will require complex surface and underground installations for loading and unloading numerous loads.

In the case of the Polish hard coal mining industry, most existing shaft hoists are driven by a Koeppe Wheel, which are not optimally adapted to lowering large loads (risk of slipping of ropes on the wheel).

5. Conclusions

Despite extensive literature on energy storage in mine shafts, there is no installation of this type using an existing shaft - there are only small technology demonstrators.

Analysing the concept of gravity energy storage in mine shafts, their functionality and feasibility, the following conclusions can be drawn:

1. It is theoretically possible to use potential energy to store energy in a mine shaft, but situational feasibility is doubtful.
2. Using an existing shaft with a shaft hoist, hoisting tower, etc. for a gravity energy storage facility makes the solution not functional due to the small amount of stored energy.
3. Increasing the scale of storage in a single shaft will require very large investment costs and may appear to be technically impossible.

Publisher: **KOMAG Institute of Mining Technology, Poland**

4. Originators of the gravity energy storage in mine shafts often ignore the legal feasibility of such a project and the constrains resulting from the operation of shafts and shaft hoists. It does not seem possible to apply provisions less restrictive than those regarding long-term operation of shaft hoists with significant intensity.
5. Technical constrains, cost-benefit ratio in relation to high legal requirements indicate that underground gravity energy storage in a mine shaft is organizationally unfeasible.
6. The number of technical problems to be solved when creating a gravity storage facility in a mine shaft makes it impossible to plan the feasibility of such an installation, which give the same functionality as ready-made battery energy storage solutions with known operational parameters and service life, which are more attractive solution.

It should be emphasized that the use of gravity for large-scale energy storage is considered as the construction of pumped-storage power plants with reservoirs located on the surface. There is also information about the intention of commercial companies to build very large battery energy storage facilities, which indicates that gravity energy storage facilities in mine shafts are not attractive from a business perspective, which undermines their economic feasibility.

References

[1] https://sdgs.un.org/2030agenda (access 02.2024).

[2] Morstyn T., Botha Ch.D.: Gravitational Energy Storage With Weights, Encyclopedia of Energy Storage. Elsevier, 2022.

[3] https://www.marketsandmarkets.com/Market-Reports/gravity-energy-storage-market-213578483.html (dostęp 03.2024).

[4] Tong W., Lu Z., Sun J., Zhao G., Han M., Xu J.: Solid gravity energy storage technology: Classification and comparison. Energy Reports, Elsevier, 2022.

[5] Jędral W.: Wytwarzanie i magazynowanie wielkich ilości energii elektrycznej w transformacji energetycznej do 2050r. Energetyka cieplna i zawodowa 5/2022.

[6] https://www.pv-magazine.com/2024/03/07/energy-vault-connects-commercial-scale-gravity-energy-storage-system-in-china/(access 10-04-2024).

[7] www.gravitricity.com (access 3-01.2024).

[8] https://greengravity.com [access: 10-02-2024].

[9] Kiliński A: Przemysłowe procesy realizacji. Podstawy teorii. WNT, Warszawa 1976.

[10] Korski J: Funkcjonalność zmechanizowanej obudowy ściana-chodnik w warunkach podporowej obudowy chodników przyścianowych. Rozdział w monografii: Mechanizacja, Automatyzacja i Robotyzacja w Górnictwie. Wydawnictwa AGH, Kraków 2022.

[11] Korski J., Korski W.: Underground mine as a system of processes. Mining – Informatics, Automation and Electrical Engineering, nr 02/2015 (electronic edition).

[12] Korski J., Tobór-Osadnik K., Wyganowska M.: Mining machines effectiveness and OEE Indicator. W: The role of Polish coal in the national and European energy sector, 19-21 June 2017, Andrychów, Poland. Bristol: Institute of Physics, 2017, art. 012010 s. 1-12.

[13] https://dictionary.cambridge.org/ [access 20-06-2024].

[14] https://meruspower.com/solutions/energy-storage/merus-ess-energy-storage-system [access 28-08-2024].

Publisher: **KOMAG Institute of Mining Technology, Poland**