Academic Journal of Science and Technology
ISSN: 2771-3032 | Vol. 7, No. 3, 2023

Research Progress of Power Generation Technology Using Gravity Energy Storage in a Context of Carbon Neutrality

Ruiqi Xiong

Rensselaer Polytechnic Institute, ECSE Department, 110 8th St, Troy, NY 12180, USA

Abstract: As the global economy improves by leaps and bounds, the skyrocketing energy consumption caused by the increase in population and rapidly developing in urbanization and industrialization has brought many serious challenges, such as global warming, environmental pollution, ecological damage, and resource scarcity. To solve these problems, countries are actively developing and utilizing energy resources to generate electricity, such as solar photovoltaics, wind, geothermal energy, ocean energy, and biomass. However, they cannot meet the growing electricity demand because of their intermittency and instability, and geographical constraints. Thus, the quest to discover innovative, sustainable, and effective modes of energy conversion and storage has emerged as one of the foremost critical concerns on the global stage. Compared to traditional electrochemical energy storage technologies, gravity storage offers higher safety, larger storage capacity, and lower environmental damage and significantly reduces the dependence on geographical conditions and water resources, with great potential for application.

Keywords: Gravity; Energy Storage; Power Generation; Research Progress.

1. Introduction

As economic and social progress continues, there is a growing need for energy. An effective strategy to reduce carbon emissions is to encourage the adoption of green energy use models in buildings. With significant progress in the large-scale application of renewable clean energy, renewable clean energy such as wind power and photovoltaic has become an important developing direction for the power industry. However, the uncertainty of the wind and light can lead to an unstable power supply and abandonment of wind and light. The power system needs to improve its regulation capacity and promote clean energy absorption. Gravity energy storage power generation technology can meet the above requirements with the advantages of environment-friendly, flexible arrangement, high safety, long service life, and non-automatic discharge.[1] This paper introduces the principle and types of the technology and reviews the research progress of the technology.

2. Principles and Types of Gravity Energy Storage Power Generation Technology

2.1. Principle of the technology

Gravity energy storage power generation technology, an emerging power generation method, has a similar basic principle with the pumped-storage technology. It utilizes stored electrical energy to lift heavy objects, thereby generating potential energy; releasing and transforming potential energy into electrical energy from a generator when needed. Four gravity energy storage technologies are available, including piston storage, suspended storage, concrete block-tower storage, and mountain energy gravity storage, which can provide sustainable energy for different environments.[2]

2.2. Types of the technology

2.2.1. Piston gravity storage power-generation technology

In recent years, with advancements in pumped storage technology, an increasing number of nations are researching and exploring new gravity storage methods. To simplify the construction process of pumped storage plants and make their logistics more manageable, scholars propose an improved scheme known as piston gravity storage technology. Abundant electrical energy can be converted into effective dynamic energy and transferred to the load by this technology. To simplify the construction and organization of pumped storage plants, some experts have suggested adopting a new technology known as piston gravity storage.

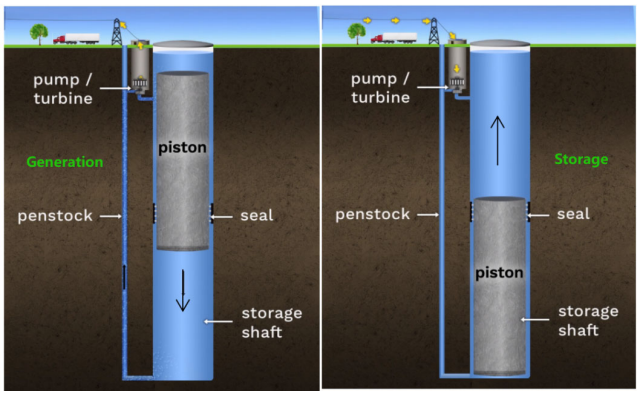

Figure 1. Piston gravity storage power-generation technology

When electricity is sufficient, piston gravity storage power-generation systems transfer gravity to the piston by converting water power to power through pumps and turbines, thus storing energy without a water body for energy storage. When generating electricity, transferring the power to the water by gravity moving the piston downwards and driving

the generator by converting the power to mechanical energy through pumps and turbines. At the same altitude and temperature conditions, the technology has higher power-generation efficiency and greater energy density because heavy objects have larger volumes. The application of the technology can make it easier to build a power station and more suitable for the siting and layout of power stations because no need to consider its geographical location and water resources. This technical solution not only retains the core equipment of the pumped storage unit but also uses advanced pump turbines with excellent performance. However, the technical aspects of the gravity piston and shaft are still to be improved. For example, what size and scale are appropriate provided the affordable economic cost? How to find the sealing solution between the two? These require continued attention to the progress of the relevant research. Currently, the technology is suitable for small-scale applications and cases for fast charging due to its limited capacity.

2.2.2. Suspended gravity energy storage power generation technology

Gravitricity Company plans to build a 250 kW advanced gravity energy storage power station in Port of Leith Edinburgh supported by its unique suspended gravity storage technology, thus achieving effective utilization of local renewable energy sources for sustainable development. The project will lift or fall 500-5000-ton drilling rigs continuously in a depth range of 150 to 1500 meters, as a means to achieve effective storage and release of electricity. When sufficient electricity is available, the drilling rigs can be towed to the top of the abandoned mines by an electric winch to convert the electricity into gravity energy; when electricity is insufficient, the generator can be driven by the hangers for drilling rigs.[3]

Figure 2. Suspended gravity energy storage power generation technology [4]

With the latest winch and control system, Gravitricity Company can greatly enhance the flexibility of its equipment and swiftly respond to power-peaking demands. The proposed suspended heavy objects by Tomas possess significant potential value as a novel technology for power storage and generation, representing a feasible solution for disused deep mines. As a machine utilizes only one load for operation, it has limitations in terms of storage capacity and the lifetime of the renewable energy source.

2.2.3. Concrete block-tower power generation technology

In 2019, the Swiss energy bank company-Energy Vault developed a new gravity storage battery that can efficiently store energy in the event of electricity shortages and convert energy into kinetic energy in the event of sufficient electricity sufficient for efficient circulation of energy under the synergy of concrete blocks and tower cranes (Figure 3).

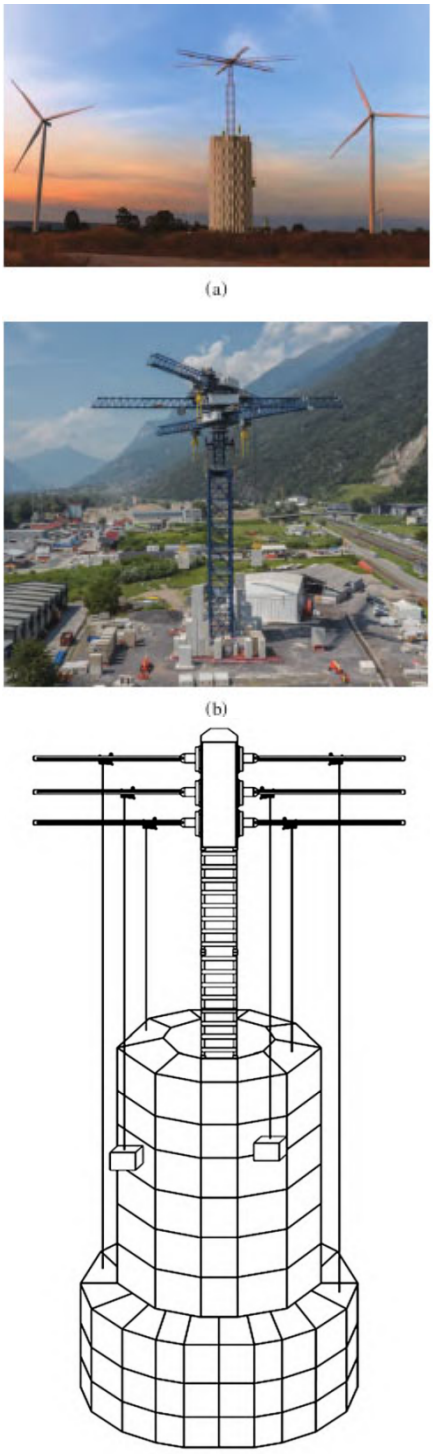

Figure 3. Schematic diagram of concrete block energy storage tower power generation technology

As shown in Figure 3, when electricity is sufficient, the crane lifts the concrete blocks stacked as blocks from the ground, thereby converting the kinetic energy within them into energy that can be stored; when electricity is insufficient, the concrete blocks are dumped in sequence, thereby releasing the kinetic energy within them and converting it into available electricity. The concrete block tower still has some potential challenges despite its simple structure. First, because of its up-and-down lifting of heavy blocks, it must be well-designed to ensure stability, reliability and safety for effective operation. Second, given its unique structural form,

a single concrete block tower is usually small in size and load-bearing capacity. Third, since each concrete block-tower stores a varying amount of potential energy at its base and top, it is challenging to ascertain how it will be lifted, stacked, and how the energy conversion will take place. It is uncertain whether it will lead to the desired outcome.

2.2.4. Mountain gravity Energy storage power generation technology

As shown in Figure 4, mountain Gravity Energy Storage (MGES) technology utilizes the potential energy from the steep mountainous terrain and gravel, resulting in effective energy use. When electricity is sufficient, efficient electric devices like ski lifts can transport containers with large amounts of gravel to the top of the mountain for electricity storage. When electricity consumption reaches a maximum, gravity is utilized to move the sand to the ground and then the kinetic energy of the sand is used to generate electricity. Studies have shown that the technology has significant advantages, with sustainability and capacity far exceeding that of conventional lithium battery storage technology. Although it appears simple and easy to implement, the relevant technical solutions remain improved and developed due to insufficient cable car systems and lower overall benefits.[5]

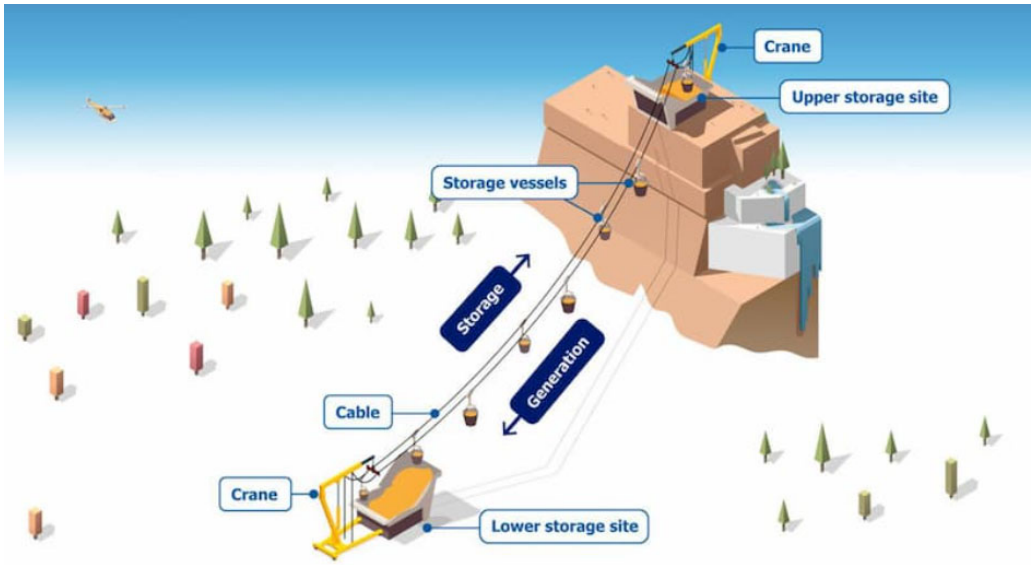

Figure 4. Schematic diagram of mountain gravity energy storage tower power-generation technology

3. Research Progress of Gravity Energy Storage Power-generation Technology

3.1. Current technological progress

Developed countries have made substantial results in gravity energy storage as Germany, the United States, and Japan are the mainstay of research & development. As early as the early 1980s, Europe began to build large-scale underground energy storage systems, such as the UK Super-grid project and the France Energy Plan project, which provided clean and efficient electricity and drove the development of related industries. Moreover, the US has been developing advanced gravity energy storage technology for military applications. For instance, utilizing capacitors with high power density as the primary energy storage component to store and discharge electrical energy; employing superconducting magnets as energy storage mechanisms to enhance energy storage efficiency.

The technology can be divided into three types - mechanical, electromagnetic, and thermal storage. They have unique advantages, characteristics, and scope of application so select a proper one according to the situation. Mechanical storage has various options, such as using compressed air, using flywheels or using gravity; electromagnetic storage consisting of super-capacitors and batteries has available methods in thermal, such as geothermal and solar energy.

China has achieved results in theoretical analysis, numerical simulation, and experimental validation in this field. Theoretical analysis is mainly concerned with modeling and simulation of the physical processes involved in gravity energy storage systems; numerical simulation refers to using computer programs to simulate the operation and performance of gravity energy storage systems under different conditions; experimental validation refers to building actual equipment as the models or schemes and testing their practical effects. However, several issues need to be addressed currently. For example, current studies have only considered the effect of a single factor like mass loading on the performance of the gravity storage system, while neglecting the role of other such critical factors as temperature variations and gas flow. In addition, how to establishing a complete and accurate mathematical model has always been a challenge because of its complex multi-coupled system.

In recent years, supported by advancing science and technology and more government policy, China's gravity energy storage technology has been developed rapidly. So far, several projects have been completed or are in the construction stage, such as "10MW/30MWh distributed photovoltaic power station of Tianjin University and 5MW power-battery storage demonstration project of Beijing University of Aeronautics and Astronautics. Meanwhile, many scholars are dedicated to exploring new materials, structures, and control strategies. It is believed that more self-developed gravity energy storage technologies will come out.

3.2. Problems

A series of challenges and difficulties in their practical

application are as follows:

(1) Low conversion efficiency of energy: the energy conversion efficiency of gravity-energy storage systems is relatively low due to their characteristics and the external environment. Therefore, it is critical to optimize their designs according to their characteristics and suitable conditions to improve energy conversion efficiency.[6]

(2) High costs: gravity-storage power plants need to invest a lot of money in their initial construction and their later maintenance compared with traditional thermal power and hydro-power. Additionally, as new energy technologies continue to advance and expand their implementation, the electricity market will see heightened competition. Thus, reducing operating costs has become an urgent issue requiring resolution.

(3) Lower safety and reliability: although gravity energy storage systems are not engaged in the combustion process as a new form of clean energy, it has a higher failure rate compared to traditional thermal power units. Serious consequences will be caused if an accident occurs. Therefore, how to further improve their safety and reliability is still one of the key issues.

(4) Lack of policy support: Despite China's efforts to promote the renewable energy industry, it has provided less policy support compared to developed countries, which has led to limited technology development and promotion in this area.

3.3. Solutions

Design optimization and control strategy appear to be working well among various improvements. In terms of design optimization, energy losses can be reduced by changing the structure and materials of the device. In terms of control strategy, more efficient algorithms need to be used to achieve real-time monitoring and management of the battery pack status. Furthermore, new materials such as nanocomposites, and carbon fiber-reinforced resin matrix composites are used in the gravity energy storage field. With higher strength and stiffness and better corrosion resistance and electrical conductivity, these materials help increase the stability of the systems.

4. Conclusion

This paper provides a thorough and detailed examination and synopsis of gravity-based energy storage technology and presents the following observations based on this analysis:

(1) Although scholars at home and abroad have carried out a lot of research on gravity energy storage materials, devices, and their applications, some problems such as how to improve system efficiency and reduce costs remain exist due to the limitations of various factors and need to be solved. Hence, there is a need to enhance the pertinent theoretical and empirical studies to enhance and refine the technology for power generation through gravity energy storage.

(2) As technology advances and environmental protection awareness increases, new gravity energy storage equipment with high efficiency and energy-saving will be widely noticed and promoted for use. It is necessary to combine it with other new energy technologies in the future to form a better clean and low-carbon energy system.

(3) The gravity energy storage power generation technology remains many challenges in its practical application, such as high prices and not better adapting to the environment. To tackle these issues, we can consider enhancing the structure of energy storage and investigating more sophisticated methods of energy conversion.

References

[1] Berrada A. Financial and economic modeling of large-scale gravity energy storage system[J]. Renewable Energy, 2022, 192: 405-419.

[2] Berrada A, Loudiyi K. Gravity energy storage[M]. Elsevier, 2019.

[3] Hou H, Xu T, Wu X, et al. Optimal capacity configuration of the wind-photovoltaic-storage hybrid power system based on gravity energy storage system[J]. Applied energy, 2020, 271: 115052.

[4] Morstyn T, Chilcott M, McCulloch M D. Gravity energy storage with suspended weights for abandoned mine shafts[J]. Applied energy, 2019, 239: 201-206.

[5] Hunt J D, Zakeri B, Falchetta G, et al. Mountain Gravity Energy Storage: A new solution for closing the gap between existing short-and long-term storage technologies[J]. Energy, 2020, 190: 116419.

[6] Moore S K. The Ups and Downs of Gravity Energy Storage: Startups are pioneering a radical new alternative to batteries for grid storage[J]. IEEE spectrum, 2020, 58(1): 38-39.