

A NEW DESIGN SOLID GRAVITY ENERGY STORAGE SYSTEM FOR RENEWABLE ENERGY

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Abstract

Climate change and global warming necessitate a shift towards renewable energy as the primary source of power. Consequently, environmentally clean renewable energy technologies are rapidly developing. However, the intermittent nature of renewable energy sources has introduced new challenges in grid integration. Addressing these issues is crucial for solving environmental problems on a large scale. To mitigate these emerging challenges, the demand for energy storage systems has increased significantly. These systems play a vital role in maintaining grid stability during the utilization of renewable energy sources and preventing energy crises. By connecting to energy networks, they store excess generated energy and return it to the grid when necessary, ensuring stable system operation. In recent years, solid gravity energy storage technologies have emerged as a promising solution among energy storage systems. This article presents a novel design for a solid gravity energy storage device. The primary objectives of this system are to facilitate large-scale grid integration of renewable energy sources and maintain system stability. Solid gravity energy storage technology offers several advantages over other energy storage technologies, including cost-effectiveness, high security, long lifespan, and increased flexibility. The development and implementation of these systems play a crucial role in advancing the energy sector and supporting the transition to renewable energy sources.

Keywords: mechanical energy storage, renewable energy, solid gravity energy storage, sustainable energy

I. Introduction

The global population growth and rapid industrial development are driving an increasing demand for energy. Both developed and developing countries are prioritizing the energy sector due to its irreplaceable role in economic growth and national development. This escalating energy demand is primarily met through two types of sources: renewable and non-renewable.

Currently, fossil fuels (oil, gas, and coal) account for the majority of global energy consumption [1,2]. Their widespread use is primarily attributed to their relatively low cost and accessibility [3]. However, despite their economic efficiency, fossil fuels are the main contributors to climate change and global warming, posing urgent challenges for all nations [4].

The environmental impact of fossil fuels is severe and long-lasting. Their combustion releases significant amounts of greenhouse gases and carbon dioxide into the atmosphere [1,3]. These emissions are the primary drivers of climate change and global warming, with fossil fuels responsible for over 75% of global greenhouse gas emissions and 90% of all carbon dioxide emissions [5].

Climate change and global warming have far-reaching consequences, affecting human health, water resources, and food security [4]. They contribute to droughts, vegetation destruction, heat waves, and increased water vapor in the atmosphere [4,6].

According to the Intergovernmental Panel on Climate Change (IPCC), the Earth's average temperature has risen by approximately 0.8°C over the past century [7]. Without significant reductions in greenhouse gas and carbon dioxide emissions, global warming is projected to exceed 1.5°C and potentially reach 2°C in the 21st century. The Paris Agreement stipulates that to mitigate these problems, greenhouse gas and carbon dioxide emissions should be reduced by 50% by 2030 and reach "net zero" by 2050 [6,8].

Renewable energy sources offer a clean and sustainable alternative to fossil fuels. Unlike their non-renewable counterparts, renewable energies produce negligible greenhouse gas emissions and have minimal negative impact on the environment and human health. These sources are inexhaustible and have the potential to meet global energy needs many times over [1,8,9,10]. The main types of renewable energy sources include:

- Solar energy
- Wind energy
- Hydroelectric energy
- Geothermal energy
- Wave energy
- Bioenergy

Renewable energies contribute significantly to reducing energy dependence and promoting economic and social development. Their availability in all countries and zero fuel costs make them an attractive option for many nations [1]. As a result, global investment in renewable energy continues to increase annually. According to the International Energy Agency, renewable energy capacity is expected to increase by 50% in 2023 compared to the previous year, reaching 507 GW. Solar, wind, and hydroelectric power are currently the most widely adopted renewable technologies [11].

Despite their numerous advantages, renewable energy sources face several [12]:

1. High initial costs: Development and installation of renewable energy technologies require substantial upfront investments [12].
2. Geographical constraints: Large open areas are often needed for wind and solar energy production, limiting suitable locations [12].
3. Production variability: Solar and wind energy depend on weather conditions, leading to inconsistent energy generation [12].
4. Energy storage: The intermittent nature of many renewable sources necessitates efficient energy storage systems [12].
5. Supply constraints: Equipment, materials, and raw materials for energy production can create bottlenecks [12].

Addressing these challenges is crucial for the widespread adoption of renewable energy and the complete phaseout of fossil fuels. Energy storage technologies play a vital role in overcoming the intermittency of renewable sources, allowing excess energy to be stored and used when needed. The development of these technologies is one of the most effective ways to combat climate change and global warming [13,14].

II. Classification and Advancements in Energy Storage Technologies

Energy storage technologies play a crucial role in the energy sector, facilitating the transition to renewable energy sources as the primary power supply and ensuring grid stability. For renewable energy to become the dominant source, these technologies must address the inherent intermittency of renewables. Energy storage systems are considered the most effective solution for achieving this stability [13,14,15,16].

These systems integrate with renewable energy networks, storing excess generated energy and releasing it back to the grid when renewable sources are unavailable, thus maintaining stable system operation [14,15,16].

Classification of Energy Storage Technologies

Energy storage technologies can be classified based on two main criteria: type and capacity.

1. Type-based classification:

- Chemical energy storage
- Thermal energy storage
- Mechanical energy storage

2. Capacity-based classification:

- Thermal energy storage
- Electrical energy storage

Among these, mechanical energy storage technology is considered more cost-effective than other types. Mechanical energy storage can be further divided into three categories (Figure 1):

1. Gravitational potential energy storage
2. Kinetic energy storage
3. Elastic energy storage

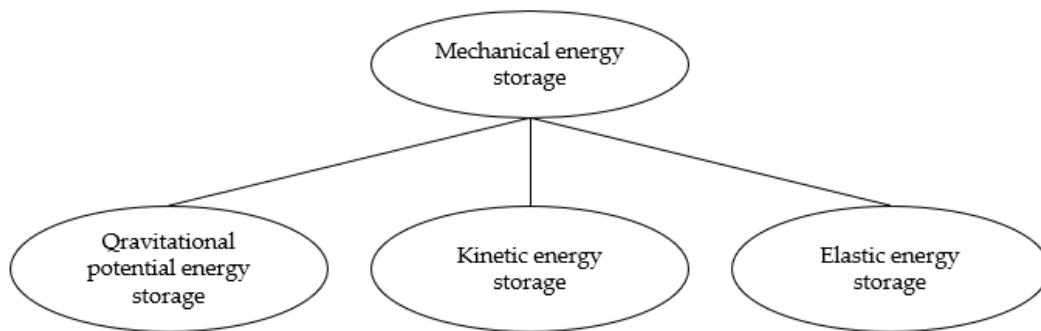


Figure 1. *Classification of mechanical energy storage technology*

Gravitational Potential Energy Storage

Gravitational potential energy storage technology comprises two main types:

1. Pumped hydroelectric power
2. Solid gravity energy storage

Solid gravity energy storage technology offers advantages over pumped storage and other energy storage technologies due to its economic efficiency and geographical flexibility. Despite being a relatively new technology, it is developing rapidly. The main advantages of solid gravity energy storage are its cost-effectiveness and long operational lifespan [14,15,16].

Solid gravity energy storage technology stores potential energy generated by changing the height of a heavy object in a gravitational field. This process involves converting excess energy from the grid into mechanical energy through an engine-generator system.

Types of Solid Gravity Energy Storage Technologies

There are eight primary types of solid gravity energy storage technologies:

1. Tower Solid Gravity Energy Storage (T-SGES) [17,18,19]
2. Shaft Solid Gravity Energy Storage (S-SGES) [18,19]
3. Rope-hoisting Piston Solid Gravity Energy Storage (RP-SGES) [20,21]
4. Mountain Mine-Car Solid Gravity Energy Storage (MM-SGES) [19,22]
5. Linear Electric Machine-Based Solid Gravity Energy Storage (LEM-SGES) [19,23]
6. Compressed Air Piston Solid Gravity Energy Storage (CAP-SGES) [20,24]
7. Mountain Cable-Car Solid Gravity Energy Storage (MC-SGES) [19,25]

8. Piston Solid Gravity Energy Storage (P-SGES) [24,26]

A critical component of these energy storage technologies is the weight system. The choice of weights significantly influences the technical performance of the storage system. Materials such as sand, concrete, and iron are commonly used due to their efficiency as weights.

Proposed Design: Novel Solid Gravity Energy Storage System

This study presents a new design for a solid gravity energy storage device specifically tailored for use with renewable energy sources, particularly solar and wind energy (Figure 2). The system utilizes excess electricity generated on the grid to lift a massive concrete block, storing energy as gravitational potential energy.

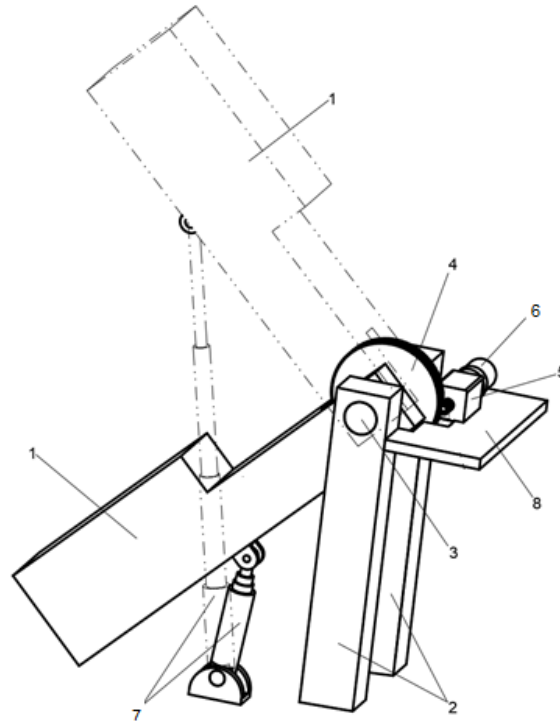


Figure 2: *New design solid gravity energy storage system*

System Components and Operation

The key components of the system include:

1. A concrete block (mass: 1000-3000 tons)
2. Concrete supports
3. A control shaft
4. A gear wheel
5. A reducer with gear wheel
6. An electric motor-generator
7. A hydraulic mechanism for controlled descent
8. A stand to keep the reducer and electric motor at a certain distance

The system operates in two main phases:

Energy Storage Phase

1. Excess energy from the grid powers the electric motor-generator.
2. The motor's rotation is transmitted through the reducer to the gear wheel on the control shaft.
3. As the shaft rotates, it lifts the concrete block.
4. The rising concrete block gains gravitational potential energy.

5. When the block reaches a defined height, the system is fully charged and disconnects from the grid.

Energy Release Phase

1. During a power shortage, the stored mechanical energy is converted back to electrical energy.
2. The concrete block descends, controlled by the hydraulic mechanism.
3. The descending motion drives the electric motor-generator, producing electricity.
4. The generated electricity is fed back into the grid.

System Specifications

- Concrete block mass: 1000 - 3000 tons
- Required construction area: approximately 300 m²

Mathematical Model

The energy storage capacity of the system is defined by:

$$E = \eta mgh \quad (1)$$

Where: E - is the energy storage capacity; η - is the system's output efficiency; m - is the mass of the concrete block; g - is the acceleration due to gravity; h - is the height change of the concrete block.

The average output power of the system is given by:

$$\bar{P} = \frac{E}{T} \quad (2)$$

Where: \bar{P} - is the average output power; E - is the energy storage capacity; T - is the system's energy discharge time.

According to expression (2), the instantaneous output power is determined by:

$$P = \frac{dE}{dt} \quad (3)$$

For circular motion of the concrete block, the average output power can be expressed as:

$$\bar{P} = M\omega \quad (4)$$

Where: M - is the torque generated during the rotation of the concrete block; ω - is the angular velocity of the concrete block.

This novel solid gravity energy storage technology has been developed to enhance the efficiency of renewable energy sources. The system's energy storage capacity can be adjusted by varying the weight of the concrete block, offering flexibility in design and implementation.

The presented energy storage device represents a promising solution in the fight against climate change and global warming, offering an efficient means of storing and releasing energy from renewable sources.

III. Results

The novel solid gravity energy storage system proposed in this study emerges as a promising solution to the challenges faced in renewable energy storage. Our analysis reveals a multitude of

advantages that collectively position this system as a potentially transformative technology in the renewable energy sector.

At the core of the system's appeal lies its structural simplicity. By incorporating straightforward components, the design facilitates easier construction and maintenance processes. This simplicity extends beyond mere ease of assembly; it translates into tangible economic benefits. The minimal maintenance requirements and streamlined construction process result in cost-effective energy storage capabilities, enhancing the system's overall economic efficiency.

One of the most striking features of the proposed system is its compact design. Unlike many traditional energy storage systems that require vast geographical areas, our system's small overall dimensions significantly reduce the space needed for installation. This spatial efficiency opens up a wider range of potential locations for deployment, from urban settings to remote areas with limited available space. Importantly, this compact design does not come at the expense of storage capacity. Our analysis indicates that the system provides substantial energy storage capacity relative to its initial cost, striking an impressive balance between size and performance.

The system's design also prioritizes longevity and safety. Its robust construction and simple mechanics contribute to an extended operational life, a crucial factor in the long-term viability of energy storage solutions. This longevity is further enhanced by the low maintenance requirements of the structural components, which do not necessitate frequent or complex technical inspections. Beyond durability, safety considerations were paramount in the system's design. The proposed configuration incorporates features that effectively reduce potential risks associated with energy storage, an essential aspect for widespread adoption in various settings.

IV. The discussion of the results

To contextualize these advantages, we conducted a comprehensive comparative analysis against existing solid gravity energy storage technologies. This comparison encompassed a range of systems, including Tower (T-SGES), Mountain Cable-Car (MC-SGES), Shaft (S-SGES), Rope-hoisting Piston (RP-SGES), Mountain Mine-Car (MM-SGES), Linear Electric Machine-Based (LEM-SGES), Compressed Air Piston (CAP-SGES), and Piston (P-SGES) systems. Our analysis focused on critical factors such as structural complexity, economic efficiency, required geographical area, energy storage density, and useful lifespan.

The results of this comparison further highlight the potential of our proposed system. Many existing technologies, while innovative, face significant limitations, particularly in terms of geographical requirements and construction challenges. They often necessitate extensive land areas for installation and present considerable hurdles during the construction phase due to their complex structural designs. In contrast, our system's compact dimensions and simpler construction process offer a more versatile solution, adaptable to a diverse range of locations and applications.

Moreover, the scalability of our proposed system emerges as a significant advantage. Its design allows for relatively easy scaling, potentially enabling customization to meet various energy storage capacities. This flexibility could prove invaluable in adapting to different energy demands and grid requirements, a crucial feature in the ever-evolving landscape of renewable energy.

While these theoretical advantages are promising, we acknowledge the need for further research to fully validate the system's benefits. Future investigations should focus on several key areas. Prototype development and testing will be crucial to validate the theoretical performance metrics presented in this study. A comprehensive cost analysis, encompassing construction, operation, and maintenance expenses over the system's entire lifecycle, will provide a holistic view of its economic viability. Environmental impact assessments will ensure the system's alignment with sustainable development goals. Optimization studies could potentially enhance

energy storage density and overall system efficiency, while integration studies with various renewable energy sources will assess the system's real-world compatibility and performance.

In conclusion, our novel solid gravity energy storage system shows considerable promise in addressing key challenges associated with renewable energy storage. Its simplicity, potential cost-effectiveness, and space efficiency position it as a valuable addition to the portfolio of energy storage technologies. As the global energy landscape continues to evolve towards sustainability, innovative solutions like the one proposed in this study could play a crucial role in accelerating the transition to a more sustainable energy future. However, it is important to emphasize that while our theoretical analysis suggests significant advantages, the realization of these benefits hinges on the outcomes of the proposed future research directions. The journey from concept to implementation is complex, but the potential rewards in advancing renewable energy storage are substantial.

However, it is important to emphasize that while our theoretical analysis and comparisons suggest significant advantages, the realization of these benefits hinges on the outcomes of the proposed future research directions. The development of prototypes, comprehensive cost and environmental impact analyses, optimization studies, and integration tests with renewable energy sources will be crucial in validating and refining the system's performance.

As the global energy landscape continues to evolve towards sustainability, innovative energy storage solutions like the one proposed in this study will play an increasingly vital role. By addressing the intermittency challenges associated with renewable energy sources, such systems have the potential to accelerate the transition away from fossil fuels and towards a more sustainable energy future. The promising results presented here provide a strong foundation for further research and development in this critical field.

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