

Systemic Analysis of The Application of Energy Storage Technology in The Power System

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Abstract. With the continuous development of new energy technology, Technology for energy storage is essential factor in the development of new energy due to the volatility, uncertainty and other factors, and the current new energy storage technology is developing rapidly. This study delves into the exploration and examination of three primary energy storage techniques: Pumped Storage Hydropower, Compressed Air Energy Storage, and Flywheel Energy Storage, elucidating their respective application landscapes. While acknowledging persistent challenges within existing new energy storage methodologies, the paper highlights an optimistic trajectory in their evolution. There is a discernible shift towards enhanced intelligence, seamless integration, and cost-effectiveness within these methods. This evolution promises to mitigate existing shortcomings and enhance the overall efficiency and reliability of renewable energy utilization. By fostering innovation and addressing key technological bottlenecks, the future of new energy storage appears promising, poised to play a pivotal role in advancing sustainable energy solutions and combating climate change on a global scale.

Keywords: New Energy Storage, Pumped Storage Hydropower, Compressed Air Energy Storage, Flywheel Energy Storage.

1. Introduction

As renewable energy sources include solar and wind energy become more and more popular their share in the energy mix, energy storage technology has become one of the important means to address the intermittency and variability of renewable energy sources. The research on new energy storage is of significant theoretical and practical significance, contributing to the achievement of sustainable energy development, ensuring energy security, and combating climate change [1].

The present study investigates multiple novel approaches to energy storage, such as flywheel energy storage, compressed air energy storage, and pumped hydropower storage. Firstly, the working principles of these methods are introduced. Then, the use of pumped hydroelectric storage in abandoned mine shafts, as well as a hybrid system combining solar PV, wind, and pumped hydroelectric storage, are analyzed as application scenarios. The analysis of compressed air energy storage includes a system that combines CAES with wind turbines, referred to as CAES in parallel with wind turbines. Additionally, a novel idea that incorporates CAES devices with offshore wind farms is discussed as another application scenario. In terms of flywheel energy storage, A new design linked to wind energy is put out that is based on a double star asynchronous machine. Furthermore, a primary frequency control method for flywheel-assisted wind turbines is explained. Finally, the study concludes with an overview of the current status and prospects of energy storage for new energy sources, providing insights into both the present state and future prospects of this field.

2. Basic principles of energy storage technology

2.1. Pumped Storage Hydropower

Pumped Storage Hydropower (PSH) is a common energy storage technology that converts electrical energy into potential energy by utilizing hydropower, storing it for later conversion back into electricity when needed. When there is excess electricity supply in the grid, electric pumps elevate water for storage from a lower reservoir to a higher reservoir. Potential energy is created when

water is pumped out of the lower reservoir using electrical energy. The water is then stored in the upper reservoir, accumulating a large volume of water, and creating high water levels and pressure. This stored water possesses potential energy that can be released when needed. When energy needs to be released, water from the upper reservoir flows down through pipes or turbines into the lower reservoir, utilizing the force of gravity to rotate turbines. These turbines drive generators to produce electricity, converting the potential energy into mechanical energy and then into electrical energy. The electricity generated by the turbines in the lower reservoir is fed into the power grid to supply electrical systems [2]. The Schematic diagram of pumped energy storage technology in figure 1.

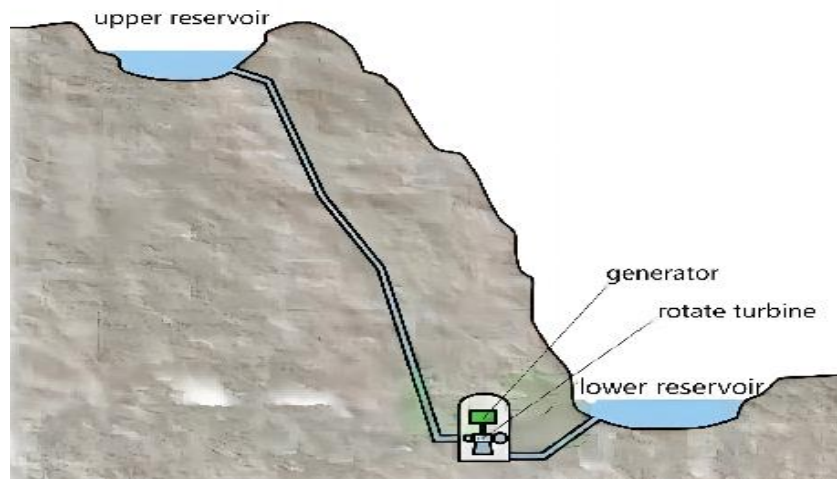


Fig. 1 Schematic diagram of pumped energy storage technology [2]

2.2. Compressed Air Energy Storage

The energy storage method known as compressed air energy storage, or CAES, transforms electrical energy into compressed air and stores it for later release [2]. Typical CAES systems consist of the following primary parts:

Compressor: A compressor is a device used to compress air into a high-pressure state. Electrically driven compressors consume electrical energy to compress air into storage tanks or reservoirs.

Storage Tanks: Compressed air is kept in storage tanks, sometimes known as reservoirs. In these tanks, compressed air is stored at high pressure until it is released.

Expander: An expander, also known as a turbine, is a device used to release the stored compressed air. When energy is required, the high-pressure air from the storage tanks is expanded through the expander, either through free expansion or by driving the rotation of a turbine, generating mechanical energy.

Generator: The expander or turbine drives a generator, electrical energy produced by transforming mechanical energy. The generator utilizes the principle of electromagnetic induction amid the stator and rotor to generate electrical current, thereby converting mechanical energy into electricity.

During the energy storage process, when the power supply exceeds the demand, the electrical system drives the compressor to compress air, transforming electrical power into stored potential energy. When energy is required, the high-pressure air from the storage tanks is released through the expander or turbine, running the generator in order to generate power, producing electrical energy from the potential energy. After the energy is released, the compressed air can be recompressed and stored again, enabling cycle reuse.

2.3. Flywheel energy storage

Advanced physical energy storage technology developed in the aerospace industry is called flywheel energy storage, it entails transforming electrical energy into mechanical energy by spinning a flywheel at a fast speed [3]. Flywheel discharge is the process of using the flywheel's kinetic energy to drive a generator through inertia and release mechanical energy that has been stored as electrical

energy. During the storage phase, the flywheel accelerates its rotation by inputting energy through an electric motor, converting the energy into rotational kinetic energy and storing it. Throughout the storage period, the flywheel maintains a certain rotational speed to preserve the stored energy. When it's necessary to release the stored energy, in the discharge phase, the rotational speed of the flywheel is gradually reduced using a braking system, converting the rotational kinetic energy into other forms of energy output. Ultimately, the rotational speed of the flywheel decreases gradually or stops altogether, simultaneously releasing the stored energy to supply the required electrical energy or mechanical power. Flywheel energy storage technology can be applied in scenarios such as energy reserves, energy balancing, and transient energy demands. It offers advantages such as high efficiency, rapid response, and long lifespan, presenting extensive application prospects in fields like renewable energy integration and power system regulation.

3. Application scenario analysis of energy storage

3.1. Pumped Storage Hydropower

Professors Yao Xilong, Ge Shuaihui, and others from Taiyuan University of Technology have proposed three feasible technical schemes for abandoned mine shaft pumped storage systems, taking into account different mining conditions: completely underground abandoned mine shaft pumped storage system, integrated above and below ground abandoned mine shaft pumped storage system, and a system utilizing the siphon effect in abandoned mine shafts [4]. In some abandoned mining areas where surface reservoirs cannot be effectively established due to factors like drought or frost, the concept of a completely underground abandoned mine shaft pumped storage system is introduced. The system and method of utilizing pumped storage found in defunct mine shafts, as illustrated in Figure 2.

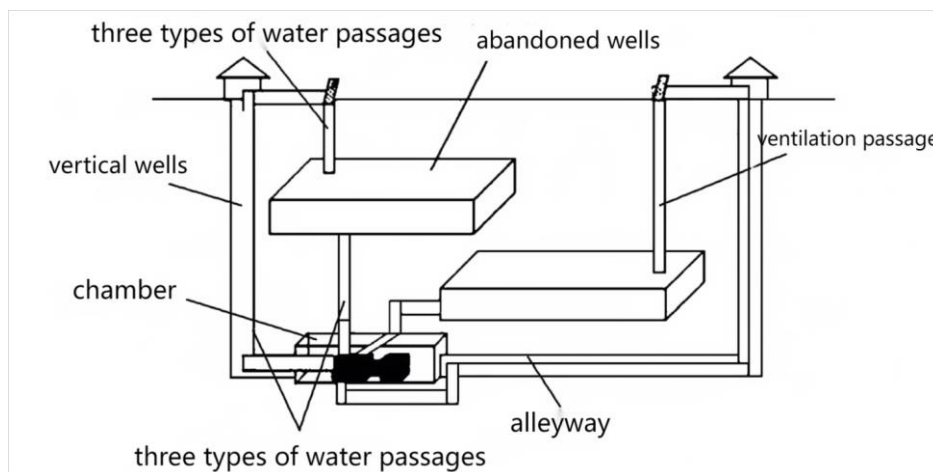


Fig. 2 completely underground abandoned mine shaft pumped storage system [4]

The fully underground abandoned well and alley water pumping and energy storage system includes two or more abandoned wells, as well as newly constructed or existing alleyways repurposed for pedestrian passage, ventilation, transportation, and equipment installation. Additionally, there are newly constructed or repurposed alleyways and chambers primarily designed for installing reversible water pumping and energy storage units, along with newly constructed or repurposed shafts for vertically interconnecting the wells. There are three types of water passages linking the reversible water pumping and energy storage units to the abandoned wells, utilizing alleyway systems, newly constructed alleys, and drilled holes. Moreover, there are ventilation passages constructed either through alleyway systems or newly constructed alleys and drilled holes to prevent the formation of high-pressure air pockets in the confined spaces of the abandoned wells during the water circulation process, thereby ensuring system efficiency.

For abandoned well alleys where it's feasible to establish reservoirs on the surface, integrated above and below ground abandoned mine shaft pumped storage system is implemented, which involves interconnecting the wells both above and below ground level. In comparison to the fully underground system, this system includes the addition of a surface reservoir. Considering various factors such as the threat of sudden influx of large amounts of water in abandoned well alleys, project volume, and construction difficulty, a system and method utilizing the siphon effect for water pumping and energy storage in abandoned well alleys has been proposed. Equipment installation and workspace for personnel are arranged above the reservoir. Utilizing the siphon effect, natural pressure, or other pressurization methods, water is induced to flow upward midway along the closed management system. Combining the above three applications with different mining conditions, three feasible schemes for water pumping and energy storage are proposed. These three technical solutions have certain value and potential in distributed energy storage and renewable energy storage, especially in areas with a high concentration of abandoned coal mines. Tajamal, et al. at ICEET proposed A combination of photovoltaic, wind, and photoelectric systems [5].

Usually, pumped energy storage systems have two reservoirs, and he proposed a system with multiple reservoirs. Through the utilization of energy from small-scale generator sets positioned in between each of the two reservoirs, the hybrid power plant's overall output power is raised. Low-power pumps transfer water from one reservoir to another, powered by the main storage of the system. Water is pumped from the higher reservoir to a specified height, then discharged into the lower reservoir. The water has more potential energy when the water level is higher than the upper reservoir. Water turbines are used to harness the energy that falls from the upper reservoir. Each pair of adjacent reservoirs generates such small units of energy. Turbulence is created on the reservoir's water surface when something falls into the next one. These turbulent flows are also used to generate electricity through turbulent turbines. By doing so, it not only enhances the electricity generation of the pumped storage hybrid power plant but also mitigates the fluctuations in wind and solar power generation, thereby complementing each other.

Chen suggested a multi-component weighting factor suppression approach that takes into account the status of the pumped storage system and the cumulative fluctuation inaccuracy of short-term PV predictions [6]. Utilizing power generating data from a 50 MW pv power station located in Xiaojin County, Sichuan Province, the suggested technique was validated. It efficiently blends solar energy and hydraulic resources in a complimentary way. Both cascade hydropower stations and FSC pumped storage power stations can serve as compensatory sources for photovoltaic fluctuations, thereby significantly reducing stabilization costs. This approach holds significant practical significance and engineering application value.

3.2. Compressed Air Energy Storage

Hasan suggests connecting CAES in parallel with wind turbines, aiming to lessen variations in wind power input and ensure a steady energy supply to the grid system [7]. Through MATLAB Simulink analysis, the parallel CAES system's efficiency under changing wind speeds was investigated, concentrating on active power and grid voltage. The outcomes reveal that, in contrast to sequentially connected CAES systems, the proposed parallel CAES configuration can effectively mitigate wind power variations and sustain continuous power delivery to the grid with less energy used when the CAES compression process is running.

Liang proposed a Multi-Dimensional CAES System with Wind Energy Storage [8]. This design greatly improves the system's economic and environmental performance by lowering the system's energy consumption expenses and carbon dioxide emissions in comparison to standard SP systems. When the optimum operating mode is put into practice, using compressed air energy storage helps to reduce the load on different devices during periods of high electricity demand, which improves the electrical adaptability of the system.

Hurley presents a novel idea that combines offshore substations supporting deep-water floating offshore wind farms with CAES technologies [9]. In order to achieve greater efficiency and cheaper

storage costs in comparison to traditional energy production methods in offshore wind farms, it suggests a solution that blends cutting-edge CAES systems with already-existing offshore technology. Within the same basic hull, the CAES Submerged Tank System (CAES-STs) can be integrated into the floating offshore substation platform. Orienting the tanks vertically, with their tips penetrating the interior structure below the fundamental hull, is the recommended method. The utilization of deepwater floating substation platforms for wind farms and CAES systems eliminates the need for onshore energy storage facilities, thereby reducing costs. Additionally, Fuel consumption and pollutants are decreased by the substation system's effective use of the compressor's recycled heat. Moreover, the substation's power need can be supplemented by steam turbine generators, which will increase overall dependability and efficiency.

3.3. Flywheel energy storage

Meriem proposed that a novel flywheel energy storage technology that uses wind energy and is based on a double star asynchronous machine [10]. In order to guarantee continuous power transmission and involvement in wind energy system services, an innovative FESS fitted with a DSIM connected to the WECM was suggested. The DSIG-based WECS employs the suggested approach. The properties of the suggested plan have been tested in different wind conditions. According to the modeling results, all wind power systems—including wind turbines and FSSS—have very good dynamic performance.

According to Tong, FESS has a variety of uses in emerging energy industries like photovoltaic and wind power generating. Energy storage systems can serve as energy storage devices in microgrid systems, facilitating the scheduling and management of renewable energy [11]. They can absorb surplus energy for future use and release energy when needed. Flywheel energy storage systems also feature high energy density and low energy loss, thereby improving the overall energy utilization efficiency of the system. It also mentions that flywheel energy storage technology has a role in frequency modulation in power systems. Jin introduces a primary frequency control method for flywheel-assisted wind turbines operating under microgrid conditions [12]. Techniques for changing pitch and virtual inertia are used to control wind turbines. In addition, an energy storage link for virtual sag containment is attached to replicate the features of conventional synchronous motors. By connecting the frequency and speed of wind turbines, this technique lowers frequency deviation and the pace at which frequency varies. Through simulation, the veracity and precision of the flywheel energy storage auxiliary wind turbine's frequency reconciliation are confirmed.

The Bendib proposes a hybrid power system that uses FESS and PHSS devices in conjunction with wind and solar energy systems as the principal sources of power [13]. The design of the recommended wind-solar/FESS-PHSS plan for a sustainable power generation system. It includes FESS, PHSS, solar photovoltaic units (SPV), and wind turbine generators (WTG). This limits the number of batteries that households without access to grid electricity can utilize to meet their basic load demands. The results show that the proposed control technique is effective and provide a thorough picture of the system's frequency and voltage changes with acceptable noise levels. The suggested model is simple to use and works well with current SPV/wind-powered systems.

4. Conclusion

With the development of science and technology, new energy storage technology is constantly improved and breakthrough, the cost will gradually decrease, and the performance will continue to improve. It can be obtained by the analysis of the above several application scenarios. New energy storage is developing towards intelligent and comprehensive development, but it also faces some problems such as reliability and safety. Overall, despite the challenges facing new energy storage systems, their prospects are still very broad and will make an important contribution to the sustainable development of the energy sector. The unstable energy supply problem must be addressed by innovative energy storage technologies because renewable energy sources are erratic and intermittent.

Additionally, there are challenges such as high construction and operation costs, low utilization rates of new energy paired with storage, and difficulties in the operation and maintenance of new storage systems. However, technological advancements, policy support, and the background of energy transition are also driving the development and progress of new energy storage. While facing these challenges, new energy storage also presents significant opportunities for development. Through continuous innovation, policy support, and technological advancements, new energy storage is expected to become an indispensable part of the future energy system, driving the energy industry towards a cleaner and more sustainable direction.

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