

Research Progress and Key Technologies of Compressed Air Energy Storage System

Yitao Shen

School of North China Electric Power University, Baoding, China

Abstract

Compressed air energy storage (CAES) has been demonstrated as the second largest energy storage technology capable of large-scale energy storage after pumped storage. Driven by the rapid development of the renewable energy industry, the electric vehicle industry and the energy Internet industry, the application scale and technical cost of energy storage systems have entered a new stage of virtuous cycle development. The physical energy storage industry represented by CAES is expected to explode Sexual growth trend. This paper explains the basic principles of the CAES system and the current research status at home and abroad. Aiming at the key issues of the traditional CAES system that are limited by geographical space and cannot get rid of fossil fuels, it analyzes and gives an improved system plan. Finally, the future development of CAES The trends and application prospects are forecasted.

Keywords

Energy storage technology; compressed air; renewable energy; research progress.

1. Introduction

With the concept of the energy Internet being proposed on a global scale, large-scale grid interconnection frees energy development from resource, space-time and environmental constraints, and promotes renewable energy such as solar, wind, and hydropower to gradually become dominant energy sources [1]. Compared with conventional energy, renewable energy has less pollution and large reserves, but its spatial dispersion, uncontrollable time and other limitations pose a huge challenge to the safety and stability of the existing power system. The dispatching and control mode of the traditional power grid can no longer meet the large-scale development and utilization of new energy. Energy storage technology has become an important way to solve this outstanding problem.

Pumped water storage and CAES are the only two energy storage methods that have been demonstrated to be able to achieve large-scale energy storage. Pumped energy storage developed earlier, with mature technology, high efficiency, large capacity, and long energy storage period. It is currently the most widely used electrical energy storage technology. However, the terrain requirements are very demanding, it is difficult to promote on a large scale, and the initial investment cost is huge [2, 3]. CAES has become a research hot spot in large-scale energy storage technology, which has the advantages of high reliability, good economy, and low environmental impact. It is expected to become an alternative technology for pumped energy storage. This article will give a brief overview of the basic principles and development status of CAES, and analyze different solutions to improve the CAES system, and finally give a further outlook on future development trends.

2. Basic Principles of CAES

CAES uses low-valley power, abandoned wind power, abandoned photovoltaic power and other electrical energy to compress air, and seals high-pressure air in underground salt caverns,

underground mines, oil and gas wells or high-pressure vessels, and releases compressed air to drive turbine power generation during peak grid load periods. It is an energy storage system based on gas turbine technology. When energy is stored, the CAES system uses electrical energy to compress air and store it in the air storage chamber; when energy is released, high-pressure air is released from the air storage chamber and enters the gas turbine. After the combustion chamber is burned with fuel, it drives the turbine to generate electricity.

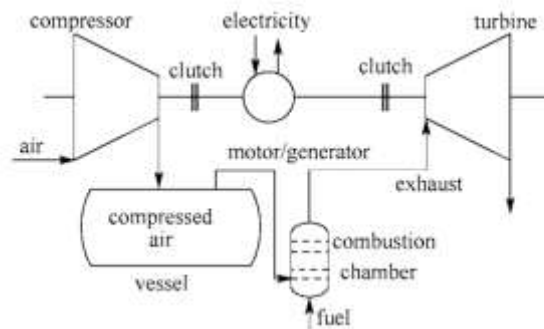


Figure 1. The compressed air energy storage system

The CAES system can make electricity production and consumption go on at the separate time to realize the "peak-shaving and valley-filling" of the grid to balance the power load, thereby improving the stability and reliability of the grid. The CAES system can "splice" sporadic, intermittent or unstable energy sources such as wind power and photovoltaics to become part of the basic load of power supply [4, 5], which can weaken or even eliminate the gradual share of renewable energy in the power supply and Increase the adverse impact on the grid.

3. Development Status

There are only two large-scale CAES power stations that have been put into commercial use in the world. The first is the Huntorf CAES power station in Germany, which was put into commercial operation in 1978. In the early days, the German Huntorf power station had a charging power of 60 MW and a generating power of 290 MW. In 2006, the Huntorf Power Station in Germany optimized the system. On the one hand, in order to improve the safety performance of the system, the inlet temperature of the high-pressure turbine was reduced from 550°C to 490°C. On the other hand, in order to increase the power generation capacity of the system, The inlet temperature of the low-pressure turbine was increased from 825°C to 945°C. The power generation of the system has been increased from 290 MW to 321 MW.

The second is the McIntosh CAES power station in Alabama, USA, which was put into commercial operation in 1991. In order to further improve the cycle efficiency of the D-CAES system, the power station adopts inter-stage cooling and post-stage cooling, and sets up waste heat recovery at the low-pressure turbine outlet, and uses this part of the waste heat to enter the high-pressure turbine. The cycle efficiency of the former compressed air preheating system is increased to 54% [6]. Compared with the Huntorf system, the gas consumption per unit of power generation can be saved by about 23%.

The Kamishawatami CAES demonstration project, which was put into operation in 2001 in Japan, is located in Sorachi, Hokkaido and has an output of 4 MW. It is an intermediate unit for industrial testing of 400 MW units developed by Japan. The American company SustainX completed the world's first megawatt-level isothermal CAES system in 2013 and started to use it. This technology uses water spray to absorb the heat generated in the compression process, which is stored in the form of hot water and injected back into the cylinder during the expansion

process. This patented technology changes the temperature, pressure and other conditions in the cylinder to keep the air almost at a constant temperature throughout the process.

China started late in the field of CAES, and there is no commercial power station yet, but it has also made great progress in recent years. Tsinghua University have completed experimental research on non-supplementary combustion CAES technology for 500 kW units, mainly focusing on the development of non-supplementary combustion. Because this technology uses compression heat to achieve reheating of the working fluid in the discharge process, basically no fuel is consumed, so there is no greenhouse gas emission during the discharge process of this technology. In 2016, the State Grid studied the implementation plan of the CAES demonstration project, and clarified the construction scale and organizational form. After the completion of Zhangbei's demonstration project, it will become the CAES system with the largest energy storage capacity in the world. The energy density of the system can reach about 100 Wh/L, which is more than 20 times the energy density of the traditional system.

4. Key Technology

With the rise and vigorous development of renewable energy such as wind and solar energy, how to safely and stably realize large-scale grid connection of new energy has become a new challenge. At the same time, with the increase in the peak-valley difference of traditional power, the stability and security of the power grid have become increasingly prominent. Although the traditional CAES system can combine and store large-scale new energy sources, it still cannot get rid of the geographical restrictions and the pollution problems caused by the consumption of fossil fuels. Therefore, after the first generation of CAES, a lot of research has been conducted on how to break geographical restrictions and get rid of traditional fossil fuel dependence.

4.1. Overcoming the Limitation of Energy Storage Space

4.1.1 Underwater compressed air energy storage

Underwater CAES uses the static pressure characteristics of water to achieve isobaric storage of compressed air. It has the characteristics of high system efficiency, small terrain restrictions, and flexible energy storage scale. It is especially suitable for offshore wind energy and other renewable energy sources. The picture shows a typical underwater CAES system [7, 8]. According to the location of the power station, it can be divided into two types: sea-based and land-based. The compressed air is stored underwater and the static pressure of water is used to maintain compressed air pressure. At present, underwater CAES has received more and more attention.

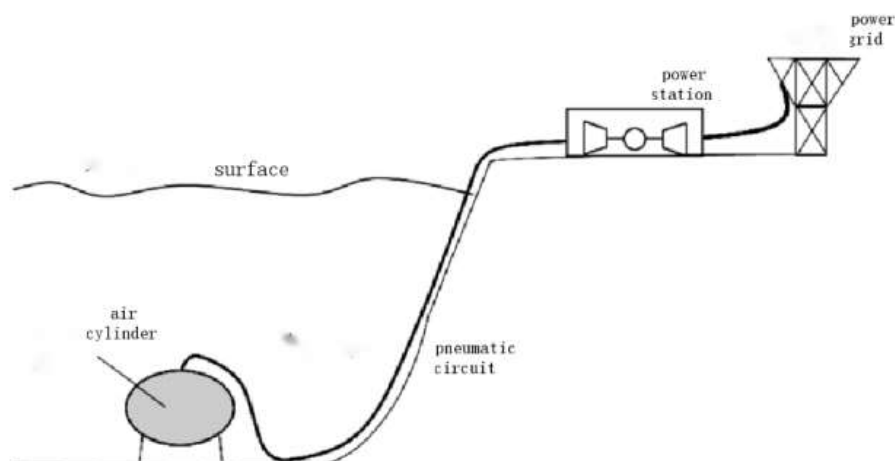


Figure 2. Underwater compressed air energy storage system

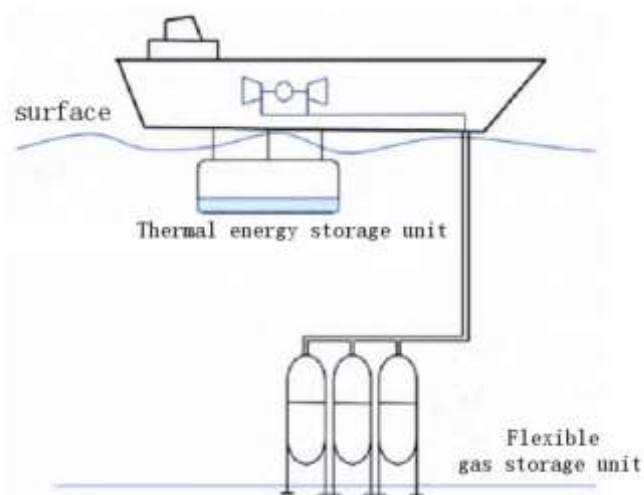


Figure 3. Underwater compressed air energy storage system with heat storage

Underwater CAES not only has the advantages of isobaric compressed storage, but also can get rid of the strict restrictions on special gas storage terrain to a certain extent. Even if a failure accident occurs, the damage and harm caused by underground CAES is small. Large-scale underground CAES usually needs to maintain a certain minimum air pressure in the gas storage cave to prevent collapse accidents due to geological instability, while the systems do not need to retain part of the compressed air to maintain the pressure in the gas storage chamber [9]. In addition, because of the similarity between CAES and some physical hydrogen storage technologies, underwater CAES can also be used as a viable option for large-scale hydrogen energy storage in the future.

4.1.2 Supercritical compressed air energy storage (SC-CAES) system

The SC-CAES is developed by the Chen Haisheng research team of Chinese Academy of Sciences to solve the problem of traditional CAES. This technology was developed on the basis of LAES technology to get rid of the dependence of CAES technology on fossil fuels and large air storage chambers. Because this technology uses supercritical compressed air as the medium, the special physical properties of supercritical air enhance the heat exchange of the system. The energy density of the system is greatly improved, which is 18 times [10] of the D-CAES system. therefore, the volume of the energy storage chamber is greatly reduced, getting rid of the dependence on the large gas storage chamber.

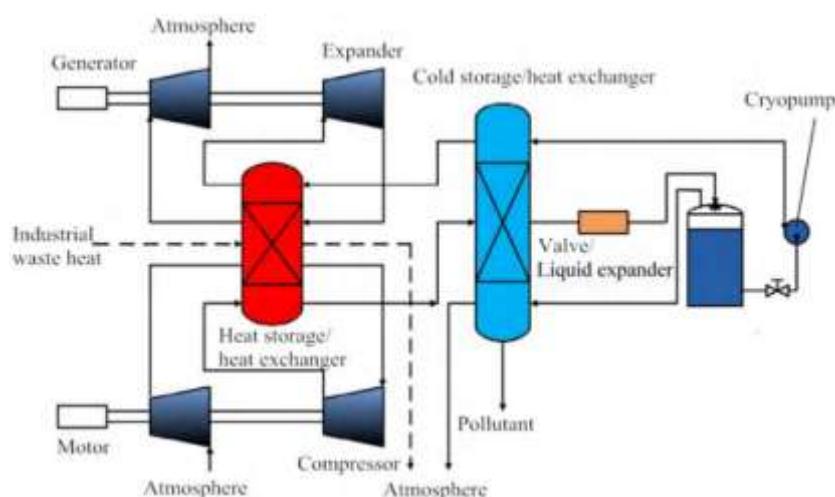


Figure 4. Supercritical compressed air energy storage (SC-CAES) system

5. Conclusion and Outlook

The CAES technology is basically mature, and it is a large-scale electricity storage technology comparable to pumped water storage methods. Due to the large scale and low cost of electricity storage, and the rapid development of wind power and photovoltaic power generation, CAES energy storage technology has been widely recognized, and different forms of CAES will surely achieve rapid development to meet the power storage needs of different levels of power grids and users. Especially supercritical compressed air energy storage technology.

Through CAES, intermittent renewable energy can be stored and released during peak power consumption, which can promote the large-scale utilization of renewable energy and provide peak power. It mainly includes CAES combined with wind power, CAES combined with solar/photovoltaic, and CAES combined with biomass [12, 13, 14]. The combination of power grids and distributed energy systems is the development trend of high-efficiency, low-carbon, and high-security energy systems in the future. Energy storage system, as a load balancing device and backup power source, is the main way to solve the shortcomings of distributed energy systems such as large fluctuations and high failure rates.

References

- [1] Yu Benshan, Sun Naida, Jiao Jiao. Current status and development trend of energy storage technology and industry[J]. Petroleum Science and Technology Forum,2017,36(01):57-61+67.
- [2] Zhang Xinjing, Chen Haisheng, Liu Jinchao, Li Wen, Tan Chunqing. Research progress of compressed air energy storage technology[J]. Energy Storage Science and Technology,2012,1(01):26-40.
- [3] Y.M. Kim,D.G. Shin,D. Favrat. Operating characteristics of constant-pressure compressed air energy storage (CAES) system combined with pumped hydro storage based on energy and exergy analysis[J]. Energy,2011,36(10).
- [4] Li Xiaomo, Qian Zegang, Yang Qichao, Zhang Chengyan, Li Liansheng. Analysis of the status quo of compressed air energy storage technology[J]. Fluid Machinery,2013,41(08):40-44.
- [5] Chen Haisheng. The characteristics and development trend of compressed air energy storage technology[J]. High Technology and Industrialization, 2011(6): 55-56.
- [6] Gayathri Venkataramani, Prasanna Parankusam, Velraj Ramalingam, Jihong Wang. A review on compressed air energy storage – A pathway for smart grid and polygeneration [J]. Renewable and Sustainable Energy Reviews,2016,62.
- [7] Giramonti Albert J.,Lessard Robert D.,Blecher William A.,Smith Edward B.. Conceptual design of compressed air energy storage electric power systems[J]. Giramonti Albert J.;Lessard Robert D.;Blecher William A.; Smith Edward B.,1978,4(4).
- [8] Brian C. Cheung, Rupp Cariveau,David S.-K. Ting. Parameters affecting scalable underwater compressed air energy storage [J]. Applied Energy,2014,134.
- [9] Wang Zhiwen, Xiong Wei, Wang Haitao, Wang Zuwen. Research progress of underwater compressed air energy storage[J]. Energy Storage Science and Technology,2015,4(06):585-598.
- [10] Mingkun Wang,Pan Zhao,Yi Wu,Yiping Dai. Performance analysis of a novel energy storage system based on liquid carbon dioxide[J]. Applied Thermal Engineering,2015,91.
- [11] Chen Haisheng, Liu Jinchao, Guo Huan, Xu Yujie, Tan Chunqing. Principles of compressed air energy storage technology[J]. Energy Storage Science and Technology,2013,2(02):146-151.
- [12] Mei Shengwei, Xue Xiaodai, Chen Laijun. Discussion on compressed air energy storage technology and its application[J]. Southern Power Grid Technology,2016,10(03):11-15+31+3.
- [13] Qin Chaokui, Yuan Jing. Development status and application prospects of compressed air energy storage technology[J]. Shanghai Gas,2017(06):35-41.
- [14] Zhang Jianjun, Zhou Shengni, Li Shuaiqi, Song Wenji, Feng Ziping. Current status and development trend of compressed air energy storage technology[J]. New Energy Progress,2018,6(02):140-150.