Current Situation and Engineering Application Prospect of Liquid Air Energy Storage Technology

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Abstract. Liquid air energy storage (LAES)technology is a new-coming energy storage method using cryogenic technology as basic theory. It managed to reach consumption of new energy in a grid-connected way, absorbing low power properly, and stable output of many other forms of energy like industrial gas and electricity. This paper introduces the technical principle and advantages of LAES, analyzes and discusses the problems faced by the development of LAES technology and the corresponding solutions, summarizes the applied fields of LAES technology. It also looks forward to the development direction of LAES technology. LAES has the advantages of high energy storage density and low storage pressure, and is less restricted by geographical conditions. It can store the remaining or discontinuous power for a certain time and produce stable power output. LAES technology has a wide range of application prospects in the power system, providing a variety of energy storage services and market opportunities for the power system, the industrial field, providing a variety of energy recovery, peak-valley balance, emergency backup and energy conversion services for industrial production, and urban gas systems, providing a variety of energy reserve, peak load emergency, emergency backup and auxiliary services for urban gas systems. It is of great significance to improve the phenomenon of "wind abandonment" and "light abandonment" in the power generation industry and meet the demand of "peak cutting and valley filling" in the power grid system.

Keywords: Liquid air energy storage, Current situation, Engineering application, Renewable energy.

1. Introduction

As an important part of social and economic development, energy is being over-consumed and has led countries around the world to experience aneconomygrowth. The consumption of fossil fuels has increased rapidly due to the increase in population and electricity demand, which has led to further depletion of fossil fuels. Therefore, countries around the world are struggling to find alternative energy sources and finding energy generation technologies [1]. In the context of achieving clean and sustainable development, deepening energy conservation, emission and greenhouse gas emission reduction, employing wind and solar power to replace fossil energy has become a global energy development trend.

Globally, renewable energy has played an important role worldwide over the past decade, with renewable energy capacity doubling from 10.1 GW in 2007 to 2017 GW in 2016. More than 200GW of renewable power capacity was added globally in 2019 [2]. In 2019, the share of renewable energy in global power generation exceeded 27.3%. Experts and scholars at home and abroad agree that by 2050, the proportion of renewable energy in the world will exceed 50%. Therefore, the development of clean energy like wind energy and photovoltaic to take the place of coal-fired thermal power is an urgent need to save energy and reduce emissions and improve people's living conditions. However, due to the instability and randomness of weather conditions, renewable energy represented by wind energy, solar energy, etc., leads to the intermittent and unstable weak points of new energy power generation.

Using energy storage technology extensively can solve the above problems effectively. Energy storage technology can transform waste resources into flexible resources. With the characteristics of storage and transfer of electric energy on time scale and space scale, it has the functions of "peak cutting and valley filling", stable power output and balance power load, so as to make up for the in continuity of operation and renewable energy power stations’output instability. Conclusively, it provides effective solutions for the large-scale utilization of renewable energy [3].

In all sorts of energy storage technologies [4], pumped storage, compressed air energy storage and large-capacity battery energy storage can be applied on a large scale. Pumped storage energy needs a watery space with potential difference and mild temperature, so it is geographically limited. Large capacity battery energy storage has problems incycle life cost-efficiency, safety, and waste disposal. Compressed air energy storage has benefit in environmentally friendly and longer life. However, it depends on surrounding landscape and suffers from low energy storage density, and is not widely used at the moment.

LAES technology is a span-new energy storage method to achieve absorbing low power properly, and stable output of many other forms of energy like industrial gas and electricity by using cryogenic technology. In 1977Smith proposed the concept of LAES for the first time [5] and with the continue innovations of LAES, it turned from concept to realizable technology. Especially in the last decade, there was a boost in research on LAES. LAES is one of the compressed air energy storages (CAES), which stores electric energy in liquid form of air under low temperature. It greatly improves the energy density of the CAES system and releases it from restrictions of environment. Moreover, the density of liquid air in the LAES system is about 80 times that of compressed air in the CAES system, and its energy storage density is at least 10 times higher than that of the 10MPa compressed air energy storage system. Nowadays, the fast development of low-temperature liquefaction technology helps researchers around the world carrying out insightful and systematic research on LAES technology, and gradually introduced the technology to the market [6-8].

This paragraph introduces the technical principle and advantages of LAES, analyzes and discusses the main technology of LAES, and shows expectations to the future development and applicationpossibilitiesofLAES.

2. LAES technology principle and advantages

2.1. Principles of LAES technology

The principle of LAES technology is to use excess electric energy or cheap grain electricity, through the low-temperature liquefaction technology to store the standard state air in the tank, and the electric energy is converted into the internal energy of liquid air and stored. When storing energy, the air is liquefied through cooling and electrical energy compression while storing the heat energy released for heating the air. When energy is released, the liquid air is compressed and evaporated to force the expander generating electricity, and when energy is stored, the cold energy is obtained to cool the air.

A conventional LAES system is made up of three interlinked subsystems that meet the periodic output of energy at different periods [9]. The system contains three subsystems including air liquefaction (energy storage subsystem), cold and heat cycle and energy release subsystem. The main equipment consists of air compressor unit, circulating compressor unit, air purification device, heat exchange/cooler, refrigeration expansion machine, heat storage and cold storage device, cryogenic pump, evaporator, expansion generator set and control system. The specific workflow of LAES technology is shown in Figure 1 [10].

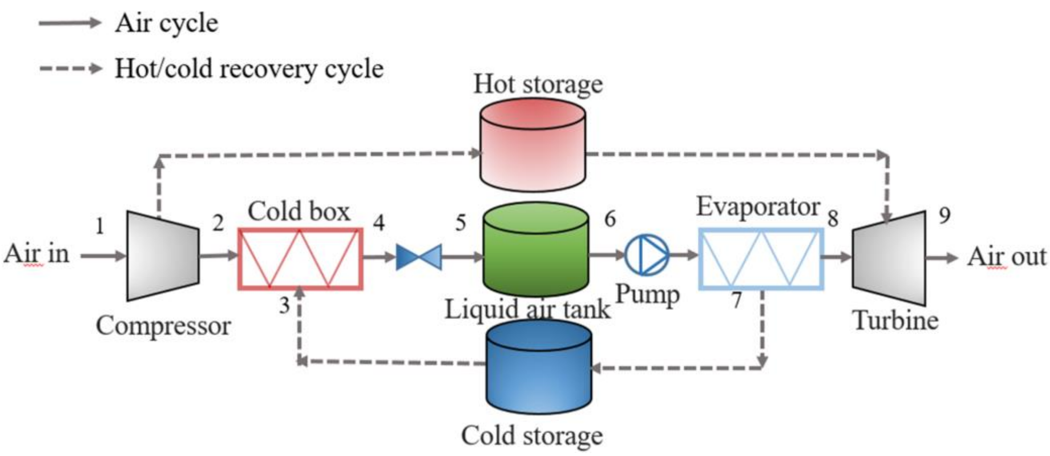

Figure 1. The working principle of a LAES system.

2.2. Advantages of LAEStechnology

The advantage of LAES technology is that compared with traditional battery energy storage technology, it has higher storage density, higher energy storage efficiency, and does not pollute the environment. LAES technology is also of great significance for the utilization of renewable energy. It can be realized by storing wind energy and solar energy and other unstable energy forms, and then converted to electricity when needed.

In addition, the LAES system can store intermittent renewable energy sources and excess electricity in the nighttime grid and has a storage capacity of 200 MW. Also, considering the preferable small size of storage devices and is less affected by the environment, it is fit for putting to use in many regions. Although it is a new way to store energy, LAES technology has developed many years started from scratch. Up to now it has mature technology. LAES system benefits the environment through minimizing the pollution, with high economic efficiency, it shows great importance in the future low-carbon market.

3. Challenges and key technologies facing the development of LAES technology

3.1. Challenges in the development of LAES technology

Although LAES technology has certain advantages in energy storage density and storage methods, the current energy storage system cannot be completely using liquefied air in the energy storage process, and the compression heat stored in the energy storage process cannot be fully used in the energy releasing process, causing overall cycle efficiency of LAES system not so high, and the equipment selection is relatively complicated. This is also the main reason for limiting the widespread application of this technology, limiting its use value, and the market recognition is not high.

3.2. Key issues of LAES technology development

3.2.1. Development of cold storage technology

LAES system usually includes two parts: air liquefaction process and liquid air energy release process. Its operation process is generally as follows: when the electricity consumption is low, through the air liquefaction process, the remaining electricity is stored in the form of liquid air, and a quantity of compression heat is also stored to increase the output power of the turbine during the liquid air energy release process; At highest power consumption, the liquid air is released, preheated by the cold storage device or the surrounding environment, and then further heated by the compression heat or other recovered high-grade heat energy, through expansion to do power generation. At present, liquefied air energy storage to improve energy efficiency mainly uses external excess heat source or cold source, and co-produces with the liquefaction process or gasification process to achieve the purpose of recycling waste heat or waste cold.

In order to accelerate the commercial application of LAES system, we must pay great attention to the cold storage technology used in LAES system. Since the main purpose of the cold storage system is for storing the amount of cold for air liquefaction, different liquefaction methods affect the structure and design of the cold storage system to a certain extent. At present, there are mainly two liquefaction methods in LAES: Claude cycle and Linde cycle. The major differences between the two liquefaction methods are as follows: Linde cycle adopted throttling expansion liquefaction method for low temperature and high-pressure air, which is characterized by long life, simple structure and lower cost. However, the energy loss is relatively large due to the mismatch between irreversible throttling process and the temperature distribution in the heat exchanger. The Crowder cycle adopts a liquefaction mode combining isentropic expansion and throttling expansion in a low temperature expander. Although the structure is relatively complex, energy efficiency is higher. On the whole, the Claude cycle is more cost-effective [11]. By improving the liquefaction mode, the efficiency of cold storage can be improved effectively.

3.2.2. LAES technology cold storage materials and equipment integration

Cryogenic storage materials and equipment technology is a major challenge, further research and development of new low-temperature storage materials and large and efficient container equipment, optimize the configuration and layout of cold storage devices, is another key factor to solve the problem of cryogenic storage capacity. In addition to the air liquefaction process, the air liquefaction energy storage technology also integrates the air storage, gasification and energy storage process, which has the characteristics of complex process flow, strong correlation between parameters and high integration difficulty. For optimizing the complementary application between systems, flexible combinations of devicesis crucial, also joint production linkage, flexible operation, and the coordination and integrity of the system improvement are also included. Advanced integration technology can not only ensure the smooth production of the device, but also minimize the energy consumption of the device.

4. Engineering application

LAES technology takes advantage of its high energy density, small footprint and good safety and stability, and is expected to be promoted and applied in various occasions according to local conditions.

4.1. Applications of LAES in power system

LAES technology has a wide range of application prospects in the power system, can provide a variety of energy storage services and market opportunities for the power system, and further promote the sustainable development of the power system. Its application is mainly in the following aspects:

(1) Energy storage balance: there are problems such as peak-valley power consumption differences and unstable renewable energy supply in the power system. LAES technology can achieve energy storage balance and make the power system more stable and reliable by storing excess energy in the power system for release when needed.

(2) Power demands: LAES technology can quickly respond to the emergency demand of the power system, when the power system load suddenly increases or the power supply is insufficient, it can quickly release the liquid air energy stored to solve the energy shortage in the power system.

(3) Auxiliary services: LAES technology can provide many supporting services for the power system like frequency regulation, reactive power compensation, voltage control and other services, so as to raise the quality of the power system.

(4) Market participation: LAES technology can use the market mechanism of the power system to carry out energy trading, and realize the economic operation of the power system by participating in the dispatch market and energy market of the power system.

4.2. Application of LAES in the industrial field

LAES technology has a wide range of application prospects in the industrial field, which can provide a variety of energy recovery, peak-valley balance, emergency backup and energy conversion services for industrial production, and further improve the energy efficiency and stability of industrial production. Its application is mainly in the following aspects:

(1) Energy recovery: Industrial processes produce a large amount of Liquid air, which contains valuable energy. Through LAES technology, the energy in this Liquid air can be recovered, thereby improving the energy efficiency of industrial production processes.

(2) Peak-valley balance: there is also a peak-valley difference in industrial power load, through LAES technology, excess energy can be stored in the of consumption peak period, and released in the power valley period, so as to achieve peak-valley balance while cutting down industrial power costs.

(3) Emergency backup: In the process of industrial production, some key equipment or systems need to be kept in operation at all times, such as lighting, ventilation, cooling, etc. Through LAES technology, emergency backup power can be provided for these critical equipment or systems to ensure the continuity and stability of industrial production.

(4) Energy conversion: LAES technology can also convert the energy in Liquid air into other forms of energy, such as electrical or mechanical energy, thus providing more energy options for industrial production.

4.3. Application of LAES in urban gas system

LAES technology has a wide range of application prospects in urban gas systems, which can provide a variety of energy reserve, peak load emergency, emergency backup and auxiliary services for urban gas systems, and further improve the energy efficiency and stability of urban gas systems. The specific application includes the following aspects:

(1) Natural gas storage: Using LAES technology, natural gas can be liquid into high pressure gas storage for release when needed. This method can greatly improve the storage density and utilization efficiency of natural gas, and reduce the occupation of storage space.

(2) Peak regulation emergency: LAES technology can help urban gas systems cope with sudden load demands, such as increased gas demand under extreme weather conditions and pipeline failures. By storing liquid air energy, the stored gas can be quickly released to meet the energy requirements of the gas system.

(3) Emergency backup: Some key equipment or systems in the city gas system need to be always in operation, such as gas pumping stations and compressors. Through LAES technology, emergency backup power supply can be provided for these key equipment or systems to ensure the continuity and stability of urban gas systems.

(4) Auxiliary services: LAES technology can also provide various auxiliary services for urban gas systems, such as providing pressure regulation, pipeline stability and other services, so as to improve the stability and reliability of urban gas systems.

5. Future development direction of LAES

LAES is a sustainable energy storage technology, and the future development direction may include the following aspects:

(1) Improved efficiency: LAES has energy loss during compression and venting, so its efficiency is relatively low. One of the future development directions is to improve the efficiency of LAES to improve its energy utilization efficiency. The application of liquefaction device variable load technology to reduce the commissioning consumption and failure risk caused by frequent equipment start-up and shutdown. Use a wider range of thermal coupling and system linkage processes to improve the overall cycle efficiency of the system and reducing dependence on external heat sources.

(2) Cost reduction: The current cost of LAES is relatively high, which limits its popularity in commercial applications. One of the future development directions is to reduce the cost of LAES in order to improve its competitiveness and feasibility of commercial applications.

(3) Application expansion: The application field of LAES is still relatively limited, and one of the future development directions is to expand its application field, such as applying it to power systems, transportation, building energy management and other fields.

In general, the future development direction of LAES will revolve around improving energy density, improving efficiency, reducing costs and expanding applications, and development and application of super-large scale cold accumulator and new cold storage materials. Joint production linkage between large air liquefaction energy storage device and other devices. This will require multiple efforts, including technological innovation, marketing and policy support.

6. Conclusion

LAES technology has the advantages of high energy storage density and low storage pressure, limited by geographical conditions, can store the remaining or discontinuous power and output it with stable power. It is of great significance to improve the phenomenon of "wind abandonment" and "light abandonment" in the power generation industry and meet the demand of "peak cutting and valley filling" in the power grid system.

Although LAES technology has certain advantages in energy storage density and storage mode, the overall cycle efficiency of the current system is not high, which limits the widespread application of this technology. In order to accelerate the process of commercial application of LAES system, paying attention to the cold storage technology of LAES system is not a second choice, strengthening the research and development of new low temperature cold storage materials and large and efficient container equipment and optimizing the configuration and layout of cold storage devices are also considerable, so as to achieve a wide range of applications in various industries.

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