

Hydrogen Energy Storage and Its Applications

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Abstract. The combination of electrolysis for hydrogen production, storage, and utilization can be effectively achieved through the use of hydrogen energy storage systems, which are designed for long-distance transportation and storage. This is due to hydrogen being an environmentally friendly energy source. In order to effectively address the current issue of "wind," this article will delve into four facets: electrolysis of hydrogen, storage techniques, fuel cells, and the utilization of hydrogen energy storage. This will enable foster efficient and sophisticated clean energy development and utilization models, and ensure the continual advancement and maturity of hydrogen energy storage. Renewable energy utilization, with its utilization of light waste, is being encouraged to be further developed and utilized. In the context of global carbon neutrality, the energy properties of hydrogen are expected to gradually emerge. As major economies around the world have successively proposed long-term carbon neutrality goals in recent years, it is expected that the energy properties of hydrogen will gradually emerge, and the application fields will gradually expand to power, transportation, construction and other scenarios. In the long run, it is expected to become an excellent form of electric energy storage. Whether in the temporal or spatial dimensions, the power system will be more diverse in the future, and the forms of energy storage will also be more diverse.

Keywords: Hydrogen energy storage, hydrogen storage technology, hydrogen energy application.

1. Introduction

According to statistics, the consumption of restricted sunlight in China as high as 162×10^8 k W·h, which causes serious energy consumption [1]. Therefore, energy storage technology began to receive attention, among them, hydrogen energy storage technology shows its advantages and it can use wind energy to convert water into renewable energy, and then store it in the solar panel, and finally can be safely put into the power supply system. The potential of hydrogen energy storage technology is immense, with the potential to enhance energy storage efficiency without any environmental issues. Especially suitable for power storage in poor villages, such as biogas generators in rural areas, seawater power hydropower stations, geothermal power hydropower stations, solar power stations, geothermal power hydropower stations, and hydrogen power hydropower stations, all can play an important energy storage effect. Hydrogen energy storage is an advanced renewable energy, which is achieved through improved methods. These methods can provide better cost performance, and can achieve better response rates through improved delivery methods. It can also achieve better reproducibility through improved equipment. This article will further discuss the global research on efficient hydrogen storage, analyze these technologies in detail from various perspectives.

The characteristics of hydrogen are remarkable - its high energy density, its convenient transportation, its lack of self-discharge, its greenness and its pollution-free nature, and so on. It can be widely used in various industrial scenarios and has been able to partially replace fossil energy in many fields.

In Europe, America, Japan and other developed countries, where investment in renewable energy is on the rise, certain areas have started to embrace this form of energy, and have been able to acquire it at a lower cost. The Danish government has even announced that by 2050, their energy production will reach 100%, which can meet the needs of various energy sources, including electricity, fuel, water, automobile energy and aviation energy. By 2050, Germany anticipates that renewable energy will comprise 80% of all electricity consumption and 60% of primary energy requirements. Meanwhile, the United States intends to have renewable energy make up 80% of total electricity by

2050 as well. Demonstrated and commercially applied in aerospace, submarines, new energy vehicles, and portable power supplies, hydrogen fuel cells have been utilized in both military and civilian fields due to their high energy density, high energy conversion efficiency, and green and environmental protection. In the future, with the further improvement of the sustainable development strategy, more support and promotion policies will continue to be promulgated, which will also drive the development of the entire hydrogen energy storage technology industry chain.

2. Methods and Steps of Hydrogen Energy Storage

2.1. Structure of Electrolyzer and Principle of Hydrogen Production

2.1.1. Electrochemical characteristics of electrolyzers

Traditional hydrogen chemical hydrogen production methods mostly use acidic substances such as KOH or NaOH, which can be directly used for hydrogen production. However, due to the acidity of these substances, their hydrogen production efficiency is low. Therefore, in general, the best condition for using this acidic substance to produce hydrogen is that the working current density of the electrolytic cell should be maintained at 0.25 A/cm^2 . With the advancement of technology, the technology of using alkaline liquid for hydrogen has become more and more advanced, and most of the traditional hydrogen storage equipment has also adopted this technology. However, due to some potential problems, for example, when the electrolyte and a large amount of carbon dioxide are mixed together, some carbonates that cannot be completely separated can be produced, thereby reducing the utilization effect of the technology. The most promising hydrogen preparation technology currently is polymer water electrolysis, with the water electrolysis hydrogen production system, constructed with a proton exchange membrane, as seen in Figure 1, being the most representative [2].

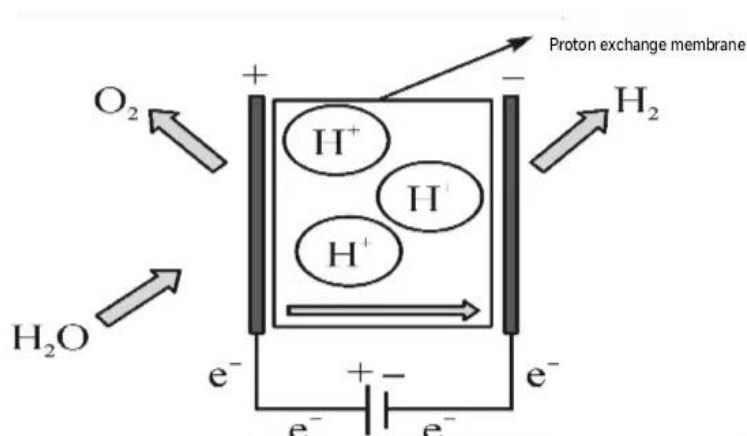


Figure 1. Hydrogen production from electrolytic cells [2].

By introducing a proton exchange membrane, the traditional asbestos membrane can be replaced and pH can be better controlled. Therefore, the acid can be used safer, and the reaction between acid and air can be prevented. After the improved electrolysis technology, the electrolytic cell in Figure 1 has a more compact structure, and the ohmic resistance is also much lower than the traditional alkaline solution hydrogen production method, which can significantly improve the overall efficiency of the electrolytic cell. In addition, the current density is much higher than the traditional electrolytic hydrogen production method, and can even reach 1 A/cm^2 . Utilizing proton exchange membrane water electrolysis hydrogen production technology, dealkalization is no longer necessary and the hydrogen produced can be securely stored in the hydrogen storage tank, thereby significantly enhancing the efficiency of hydrogen production and enabling the effective utilization of hydrogen energy from the electrolytic cell.

$$M_{el}(t) = \eta_{el} P_{el}(t) \quad (1)$$

In this formula, M_{el} represents the electric power required by the electrolytic cell that uses the proton exchange membrane water to electrolyze hydrogen at time t , P_{el} represents the power of hydrogen production, and η_{el} represents the energy transfer rate of the hydrogen production process.

2.1.2. Thermodynamic characteristics of electrolytic cell

When the electrolyzer is used to accelerate the reaction, it may release more than 80 °C of energy, so its energy consumption may not be considerable. To guarantee the successful completion of the reaction, the industrial park must take steps to reduce energy consumption, such as cooling, to ensure the safe utilization of hydrogen, despite its minimal energy consumption. Therefore, the energy conversion of the electrolytic cell part is not only limited to transferring the heat energy from the electrolytic cell to the cooling water, but also can be obtained from the hot water of the cooling circulating system, thereby effectively supporting the energy utilization of the industrial park.

2.1.3. Connection mode and efficiency of electrolyzer

The large-scale application of electrolytic hydrogen production equipment needs to consider the connection mode of electrolytic cells. A series-parallel combination is embraced, that is, multiple electrolytic cells are linked in parallel, and each of these cells in parallel is made up of multiple electrolytic cells in succession. The connection mode is shown in Figure 2 [3].

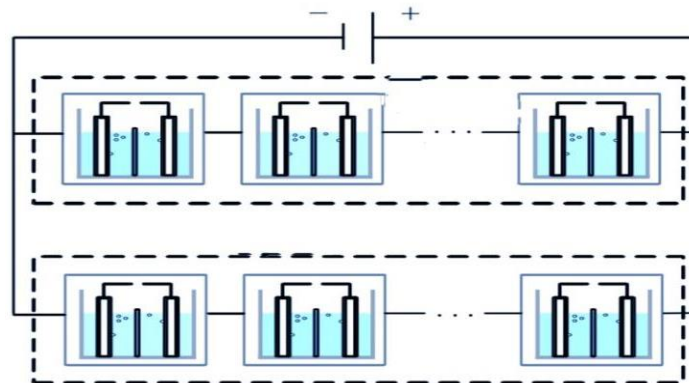


Figure 2. Connection mode of electrolyzer [3]

The efficiency of the electrolytic cell is generally expressed by the voltage efficiency η_e , which is about 50%~60% [4]. The utilization efficiency of electric energy in the electrolytic cell is only demonstrated by voltage efficiency, and it cannot accurately demonstrate the correlation between the potency of rapid hydrogen production and the quantity of hydrogen produced. The formula displays the total efficiency of hydrogen production, which is represented by the total hydrogen production efficiency η . This efficiency is determined by the amount of hydrogen produced per kilowatt of electric energy and the ratio of the energy in the generated hydrogen to the energy needed for the water electrolysis process.

$$\eta = \eta_e \times \eta_y \tag{2}$$

The hydrogen production of the electrolyzer can be calculated as follows:

$$N_{H_2} = \sum P_{eli} \times \eta \tag{3}$$

Where N_{H_2} is the hydrogen production (kmol); P_{eli} represents the hydrogen production power (KW) of the i -th electrolyzer.

2.2. Hydrogen Storage Technology

2.2.1. Generalization of hydrogen storage technology

A plethora of distinct pathways can be taken to realize hydrogen storage technology, comprising two distinct types: physical and chemical. Among them, physical hydrogen storage technology can be realized by using liquid hydrogen, high-pressure hydrogen, activated carbon absorption, carbon fiber or carbon nanotubes. The chemical hydrogen storage technology can be achieved by using metal hydrides, organic liquid hydrogenates or inorganic chemicals. Exploring more scientific and advanced methods to evaluate the performance of hydrogen storage technology, such as the density coefficient, is a goal of the International Renewable Energy Agency, World Energy Network (WENET), and numerous other international organizations and companies. volume, the mass ratio, the duration of the hydrogen charging and discharging reaction process, the efficiency of hydrogen charging and discharging, the duration of reusability and the degree of safety. At present, the relevant specifications published by the U.S. Department of Energy (DOE) are more reliable. Therefore, in order to achieve the best industrial applications, the best hydrogen storage technology must have the best hydrogen content, the best bulk density coefficient, the best absorption and release capacity, the shortest cycle life and the best safety and reliability characteristics. According to the current level of technological development and demand, three methods of high-pressure storage, liquefaction storage and metal hydride storage can meet the needs of commercial applications.

2.2.2. Main methods of hydrogen storage

(1) High pressure gaseous hydrogen storage technology

High-pressure gaseous hydrogen storage is a technique that uses high pressure to retain hydrogen in a liquid. The characteristic of this technology is that it does not need to use any external equipment, only a small space can be completed. Its biggest feature is that its operation is very simple, and it has many advantages. For example, its energy consumption is very small, the cost is very low, and its hydrogen charging and discharging speed is very fast. In addition, it has strong adaptability, even in extremely cold conditions, it can still operate. Because of its excellent performance, high-pressure gas storage technology has become completer and more feasible.

With the advancement of technology, traditional high-pressure gaseous hydrogen storage containers are no longer able to meet current needs. Therefore, more advanced technologies are being used, such as using more advanced materials, using more advanced sealing technologies, and smaller container sizes to meet current needs. Studies have shown that the use of multi-layer structure of the full composite filament winding technology can greatly improve the performance of low temperature, low pressure, multi-functional hydrogen storage container, including the inner layer, middle layer, outer layer, and other layers, each layer can play a unique function.

High-pressure hydrogen is used in a wide range of applications, including solid, liquid and gaseous. Especially in the automotive industry, its use is very common. Most of the gas cylinders used are made of strong metal liner and woven from glass fiber. At present, 35MPa high-pressure hydrogen tanks have been very successful, and Toyota Group's 70MPa high-pressure hydrogen tanks have also been widely used in the design of ordinary vehicles, as listed in it [5]. In view of economic factors, under the 70MPa aerodynamic standard, the connection between hydrogen storage and aerodynamics has become very small. Even if the aerodynamics is doubled, the hydrogen storage can only be increased by 40-50%. However, as the pressure difference increases, it will also bring more stringent pipeline width restrictions, thereby reducing the burden of space and thereby reducing the efficiency of hydrogen storage. After precise calculation, the pressure range is between 55 and 60 MPa, which can achieve the best economic benefits. However, due to the complicated structure and huge volume of large-scale high-pressure hydrogen storage tanks, the pressurization space is relatively limited, and dangerous problems such as hydrogen leakage and vessel burst may also occur.

(2) Liquefied hydrogen storage technology

Also known as liquid hydrogen storage technology. The technology is to cool pure hydrogen to 20 K to liquefy it, and then install it in a "low temperature storage tank" for storage. In order to reduce

the loss in the working process, the liquid hydrogen storage tank must be a vacuum insulated double-walled stainless-steel container. In addition to maintaining a vacuum between the double walls, thin aluminum foil should be placed between the double walls to prevent radiation. This technology has the advantage of high hydrogen storage density. However, because hydrogen liquefaction is very difficult, resulting in higher liquefaction costs. The second is the high thermal insulation requirements of the container, which makes the volume of the liquid hydrogen cryogenic storage tank about twice that of the liquid hydrogen. Liquefied hydrogen storage technology is mainly used in high-end technologies, such as aerospace.

Liquid hydrogen storage tanks are generally divided into two layers, inner and outer. The inner tank contains liquid hydrogen at a temperature of 20 K. It is placed at the center of the outer shell through a support and supported by glass fiber, with strong insulation ability. The interlayer is filled with multiple layers of aluminum plated polyester film to reduce thermal radiation. Place insulation paper between each film to increase thermal resistance and absorb residual gases at low temperatures. Using a vacuum pump to remove the air inside the interlayer, forming a high vacuum can prevent gas convection and heat leakage; The liquid injection pipe is coaxial with the gas discharge pipe, both made of materials with low thermal conductivity and coiled in a interlayer, thus greatly reducing heat leakage through the pipeline. Materials such as aluminum alloy and stainless steel typically form the inner lining of the storage tank, while low-carbon steel and stainless steel are usually used for the outer shell. Aluminum alloy materials can also be used to reduce the weight of the container.

In choosing a hydrogen storage method, people need to consider its economic benefits. Generally speaking, when the amount of hydrogen storage is large enough, the cost of using hydrogen as a hydrogen storage method will be less than the cost of using hydrogen. In the choice of hydrogen storage method, we usually choose to use vacuum super insulation technology, this technology can effectively reduce the evaporation loss, and can provide better hydrogen storage effect. When vacuum powder is used as a hydrogen storage material, its evaporation rate is usually between 1~2 wt%/d. In general, the storage cost of liquefied hydrogen storage is quite expensive, and its safety requirements are quite strict.

(3) Metal hydride hydrogen storage technology

By using special metal hydride hydrogen storage materials, people can store and release hydrogen. This material is usually composed of a special metal material or other chemical substance, and it stores hydrogen under high heat conditions. Its hydrogen storage density is more than 1,000 times that of ordinary hydrogen, and it has better reserves than ordinary hydrogen, even. The hydrogen storage tank is a multi-functional hydrogen storage device, which can not only store hydrogen energy, but also provide hydrogen energy to other equipment. The advantages of this kind of hydrogen storage equipment are: strong hydrogen storage capacity, small hydrogen storage container volume, high hydrogen storage efficiency, and it is very friendly to industrial production and consumers. The hydrogen storage tank includes 5 parts: hydrogen storage material, storage tank, heating device, discharge device and control device. Their common structures can refer in Figure 3; (a) a conical storage tank, (b) a pressurizing device is installed in the storage tank, (c) the storage tank is divided into several storage tanks, (d) honeycomb storage tank [6-8].

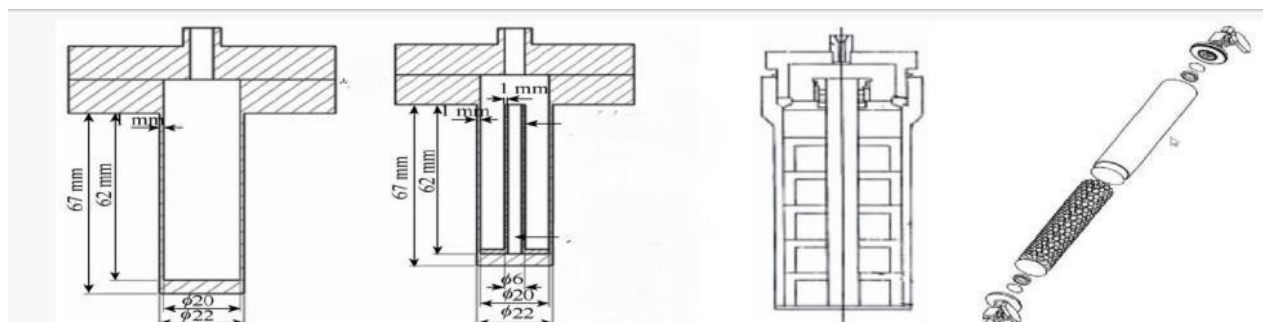


Figure 3. (a) It is a cylindrical cavity (b) with a gas duct inside it (c) divided into multiple chambers (d) with a honeycomb shape [6-8].

At present, some defects of metal hydride hydrogen storage device limit its application: First, the device is easy to lose powder, hydrogen will appear after volume expansion, resulting in device deformation or damage. Secondly, due to its low thermal conductivity, it will reduce the internal temperature exchange of the device, thereby reducing its hydrogen absorption and hydrogen release effects. In the past few years, the research on metal hydride hydrogen storage tanks has been committed to solving two key problems.

2.3. Structure and Working Principle of Fuel Cell

2.3.1. Structural composition of fuel cell

Hydrogen gas kinetic energy battery consists of four components: 1. Anode: When hydrogen is added to the gasoline kinetic energy battery, it can catalytic activity, a large number of electrons, ions into a usable form; 2 cathode: when the form of these forms is transformed into a usable form, it can be through the external integrated circuit, a large amount of electrical energy into a usable form; 3 Electrolyte: When affected by electric current, various metal molecules can be converted into usable forms through electrolyte, thereby forming usable forms, such as water, temperature, and light. 4 External integrated circuits: Through these forms, available forms can be used to provide electrical energy for production plants. Through the use of electric heating and gas coupling technology, the heating characteristics of hydrogen fuel cells have been greatly improved, thereby greatly increasing the energy conversion effect of traditional hydrogen fuel cells from 40% to more than 80% [9-11]. Hydrogen kinetic energy conversion model for hydrogen fuel power generation:

$$P_{fc}(t) = \eta_{fc} \times M_{fc}(t) \quad (4)$$

In this formula, M_{fc} represents the power of hydrogen consumed in time period t , P_{fc} represents the power of power generation, and η_{fc} represents the energy conversion efficiency when hydrogen is consumed.

2.3.2. Thermodynamic characteristics and efficiency of fuel cell

Hydrogen fuel cells can generate a large amount of heat, which is more considerable than the heat emitted by the electrolytic cell. At present, the thermal management technology of hydrogen fuel cell mainly includes liquid cooling and air cooling. The former uses the coolant in the bipolar plate to transfer heat to the battery, while the latter uses air convection heat transfer to transfer heat to the battery. Inside. When the room temperature reaches 26 °C and the atmospheric pressure remains at 1 standard, according to the characteristics of the hydrogen fuel cell, we can calculate the voltage corresponding to the maximum heat generated [2]:

$$E_h = -\Delta h / 2F \approx 1.48 \quad (5)$$

When a current flows through a hydrogen fuel cell, the voltage of the cell will decrease. Assuming that the voltage of the hydrogen fuel cell in the industrial park is V_c at a certain time, the working efficiency of the cell is:

$$\varepsilon = (1/\tau) V_c / V_h \quad (6)$$

τ is the excess coefficient of hydrogen fuel. According to this formula, the hydrogen fuel cell can provide 1 kW·h of electricity, and the heat it releases is about 5 400 kJ, or even less.

3. Application of Hydrogen Energy Storage Technology

3.1. Overview of the Application of Hydrogen Energy Storage Technology

The dual carbon target of "carbon peak, carbon neutrality" is significantly reduced by hydrogen energy's environmentally friendly energy storage system, allowing for long-distance energy storage. This has a critical role in reducing the carbon pressure of China's power industry. This article delves into the power field of hydrogen energy storage, analyzing the key technologies in the system and then concentrating on its application in the power industry. Thus, based on the hydrogen energy storage technology, this analysis is conducted. Through research, it can be known that the hydrogen energy storage system can meet the power supply needs of the power industry, enable it to smoothly apply clean energy in the process of power distribution and power supply, and provide assistance for the realization of the dual carbon goal.

3.2. Application Scenarios of Hydrogen Energy Storage Technology

3.2.1. Wind and photovoltaic power generation

The estimates of the China Hydrogen Energy Alliance show that China's hydrogen energy consumption is expected to exceed 3.5×10^7 t billion tons in 2030, or even higher. In addition, the popularization of hydrogen energy makes the global carbon emissions is also expected to drop to 700 million tons $\times 10^8$ t. The power system is one of the industries with huge energy consumption. The application value of hydrogen energy storage technology in power production is very prominent, and it is of great significance to the power industry to achieve the dual-carbon goal.

In recent years, the proportion of new energy in China's power production has increased. By 2021, the installed capacity of new energy power generation such as wind power and solar energy will reach 7.26×10^8 kW, wind power generators will be about 3.28×10^8 kW, and solar power generators will be about 3.07×10^8 kW. However, due to the limited power resources output by new energy sources, and under the conditions of continuous no wind and no light, it will face a large area of power shortage. On this basis, hydrogen energy storage technology can be applied to the power system, using hydrogen energy as a regulating resource for wind power and solar power generation [12].

3.2.2. New power system

To foster the long-term growth of Chinese power production, a new energy system should be constructed with fresh energy as its foundation. Hydrogen energy storage technology can be applied to a new type of power system, using electric energy that cannot be directly connected to the grid during power production to produce hydrogen, to achieve hydrogen energy storage, so that it can be used as a substitute and supplementary energy after new energy consumption problems [13]. By 2020, the utilization of waste water, waste gas and waste light energy had risen to 3.01×10^{10} kWh, 1.66×10^{10} kWh and 5.26×10^9 kWh respectively. Taking into account the fuel consumption per kWh, China's waste gas energy can also be converted into 9.28×10^5 t of green energy. The power industry can, through hydrogen energy storage technology, employ hydrogen-based fuel cells to satisfy the power system's requirements after hydrogen production has been completed.

Through proton exchange membrane electrolysis technology, the hydrogen energy storage system can meet the efficient energy demand from 0 to 0-160%, and its cold start time only takes 5 minutes. Therefore, it can timely track the operating status of wind farms and photovoltaic power plants. When the electricity consumption reaches its peak, it can convert it into electricity, and when the electricity consumption reaches the minimum value, it can also convert it into electricity, greatly improving the effectiveness of new energy use, and enabling it to be widely used for the construction and operation of power plants.

The growing popularity of hydrogen energy storage technology allows for the accurate estimation of wind farms and solar power plants' operating status, thus allowing for the efficient distribution of power resources and minimizing the grid's detriment caused by the introduction of wind and solar power plants. The power grid's safety necessitates more precise energy consumption forecasting, due

to the perpetual emergence of fresh energy sources. After the application of hydrogen energy storage system, its own rapid response and large capacity characteristics can reduce the planned curve of power system output and reduce the deviation of power production and power resource supply by tracking and compensating the actual power of wind and solar [14].

3.2.3. Power grid operation

Hydrogen storage can also meet the requirements of power system peak shaving capacity and alleviate the congestion of transmission and transformation lines during the operation of the power grid.

The power grid's capacity to adjust peak load is necessitated by the influx of new energy sources, such as wind and photovoltaic. Nevertheless, the power industry's large-scale introduction of new energy has drastically altered the power system's consumption structure, resulting in a widening of the peak-to-valley difference during the grid's operation. For example, it is estimated that in 2030, the capacity adjustment gap of my country's power grid will not be less than 1.2 billion kW; and in 2050, the peak shaving capacity gap will reach 2.6 billion kW. Hydrogen energy storage technology, as a technical means to meet the need for large-capacity and high-density storage, can be used to enhance peak shaving service of the power grid and bridge the capacity gap during its operation.

The demand for electricity in certain regions of China has grown significantly due to the enhancement of regional economic conditions, yet local power transmission capacity is not expanding. Consequently, when the power supply is at its highest, the transmission and distribution system will be congested, thus posing a risk to the safety of the system. The large-capacity hydrogen energy storage system can be used as a "virtual transmission line" at this stage to release electric energy in time when the power demand is large, and relieve the power supply pressure of the transmission and distribution system.

3.2.4. Meet the demand for electricity

Through hydrogen energy storage technology, the power system can more flexibly respond to power demand, so as to achieve "load with the source", "source-load interaction", and can effectively regulate the power supply, so as to solve the problem of mismatched power in the power system. The hydrogen energy storage system can be used as an emergency backup power source for the power system. At this stage, in Chinese power industry, diesel generators and lithium batteries are the main emergency power systems for power supply. However, diesel generators have serious pollution, high carbon emissions, and high equipment noise during power production. Lithium batteries have low energy density, short life and weak endurance. When hydrogen energy storage technology is applied, the advantages of low pollution, silence, long battery life, and green manufacturing of hydrogen energy storage power supply are more obvious. Therefore, in Chinese emergency backup power supply, mobile hydrogen fuel cells are gradually being used in photovoltaic applications. It is reported that China's first "Mangrove"-grade hydrogen fuel cell, with a power of more than 120kW, provides a strong support for the fight against "Mangrove".

4. Conclusion

Hydrogen energy storage is achieved by storing renewable energy for power generation or surplus electricity for electrolysis of water to produce hydrogen gas (green hydrogen), and converting the stored hydrogen gas into electrical energy through fuel cells when needed. Hydrogen storage technology is a vital element in the long-term storage of energy, and can regulate wind, solar, and clean energy across day or even season. It is essential for the successful application of this technology, which must meet the criteria of safety, efficiency, small size, light weight, low cost, and high density. At present, the storage method of hydrogen energy still has a long way to go before it becomes practical, and it has become one of the bottlenecks in the large-scale application of hydrogen energy. It is deemed that metal hydride hydrogen storage technology, with its large bulk density, excellent safety performance, and low cost, is the most suitable choice for the application of hydrogen energy

storage, taking into account the pros and cons of various hydrogen storage methods. The utilization of high pressure metal hydride hydrogen storage technology, which has the most comprehensive performance advantages and requires further refinement, is highly advantageous in the field of hydrogen energy storage and can be applied to large-scale research. Despite this, hydrogen energy storage remains of great importance for the storage of renewable energy, the formation of new energy in China, and the realization of the "dual carbon" goal.

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