Scientific and Social Research, 2024, Volume 6, Issue 4
https://ojs.bbwpublisher.com/index.php/SSR

Analysis of Current Utilization of Hydrogen Energy

Zhefeng Liu[1]*, Kai Wang[1], Yang Wang[2]

[1]China Electric Power Engineering Consulting Group East China Electric Power Design Institute Co., Ltd., Shanghai 200063, China

[2]Carbon Neutrality Development Research Institute of CPECC (Industry Planning Research Center of CPECC, New Electric Power System Research Center OF CPECC), Beijing 100029, China

***Corresponding author:** Zhefeng Liu, dw108@126.com

Abstract: Hydrogen energy is recognized as a clean energy with the characteristics of convenient storage and transportation, diverse utilization ways, and a high utilization rate. It can help to solve the energy crisis, global warming, and environmental pollution. At present, many countries have listed hydrogen energy as an important part of the national energy system. This paper comprehensively considers the application of hydrogen energy in the field of energy and chemical industry, and summarizes the utilization status of hydrogen energy in the country and abroad as a clean renewable energy carrier in fuel cell vehicles and fuel cell forklifts. The utilization of hydrogen clean energy as an energy carrier is conducive to the collaborative development of renewable energy. It is pointed out that hydrogen production, storage and transportation, and fuel cell technology are still the key factors restricting the development of hydrogen energy.

Keywords: Hydrogen energy; Clean energy; Energy carrier; Green hydrogen

Online publication: April 29, 2024

1. Introduction

Coal, oil, natural gas, and other fossil fuels are the main energy sources in today's society. With the continuous increase in total energy consumption, the world is facing the dilemma of decreasing fossil fuel reserves and increasing difficulty in extraction. The study believes that global oil production and natural gas production will only decrease after the peak in 2020, and the ensuing supply shortage is bound to cause global oil and gas prices to soar [1]. Hydrogen has the characteristics of clean and pollution-free, convenient storage and transportation, high utilization rate, and direct conversion of chemical energy into electric energy through fuel cells. Hydrogen also has a wide range of sources and various ways of production [2].

With the continuous improvement of battery technology, the emerging industries based on fuel cells will maximize the clean utilization of hydrogen energy, which is mainly manifested in the industry of hydrogen fuel cell vehicles, distributed power generation, hydrogen fuel cell forklifts and emergency power supplies. Besides, hydrogen energy is a good energy carrier that is clean, efficient, and easy to store and transport. Renewable energy, especially wind and solar energy have developed rapidly in the past ten years, but their instability causes inconsistent power generation, which have seriously restricted their development [3]. The excess electricity generated from wind, and solar energy can be used for electrolytic hydrogen production as a type clean energy, which can be incorporated into the natural gas pipeline network transport for use.

2. Renewable energy application with hydrogen as the carrier

The development and utilization of wind energy and solar energy are affected by intermittency and unpredictability, resulting in a large amount of energy waste, which seriously restricts their development. Hydrogen energy is a good energy carrier. So the use and utilization efficiency of wind and solar energy can be improved by converting wind and photovoltaic electricity into hydrogen through electrolytic hydrogen production as shown in **Figure 1**.

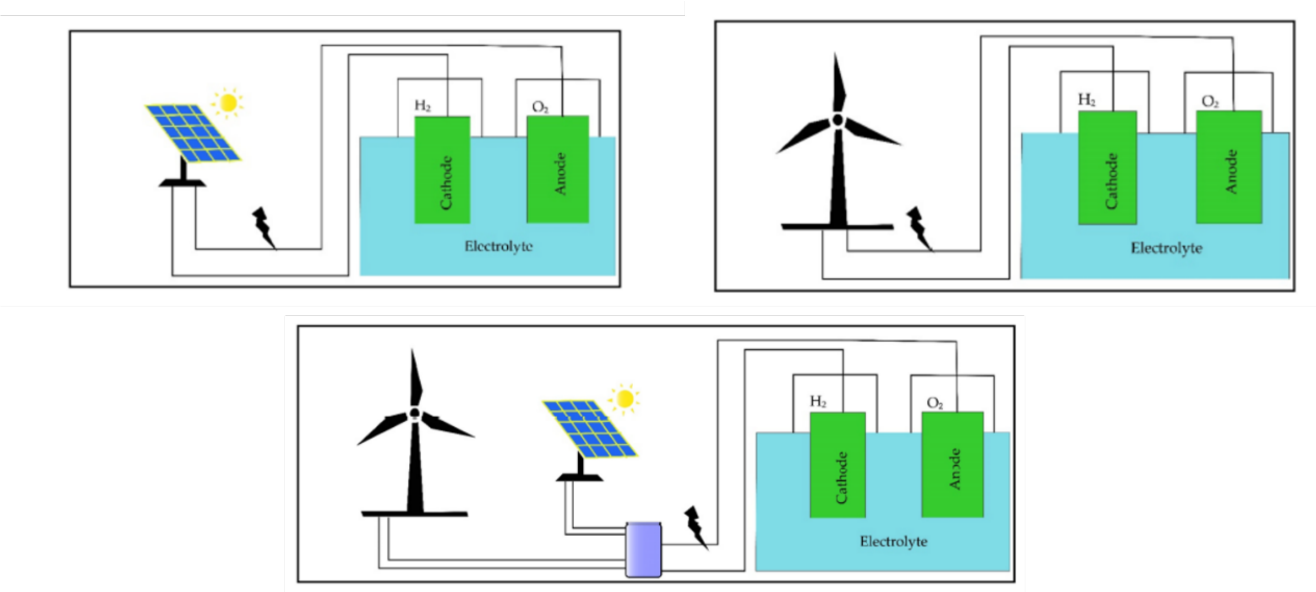

Figure 1. Hydrogen production from hybrid energy-based electrolysis

2.1. Renewable energy consumption

Renewable energy such as wind and solar energy has developed rapidly in recent years and has become one of the important energy sources in some countries and regions. The global installed capacity of wind power in 2013 was 35 GW, and the cumulative installed capacity reached 318.12 GW, among which China's installed capacity of wind power reached 16.09 GW, with a cumulative installed capacity of 91.4 GW, ranking first in the world. In the same year, the global installed capacity of solar PV exceeded 36 GW, and the cumulative installed capacity exceeded 132 GW, among which China's grid-connected installed capacity was 11.3 GW, and the cumulative installed capacity was 18.1 GW, also ranking first in the world. However, the instability of wind energy and solar energy has caused the wind farms to be abandoned. According to statistics in 2013, the amount of potential energy wasted in abandoned wind farms alone exceeded 16.2 billion kWh, and the abandonment rate reached 10.74%

Energy storage is key to the development of renewable energy. Renewable energy storage technologies mainly include battery storage, compressed air storage, pumped storage and hydrogen storage. Through comparison, it is found that when the cost of hydrogen storage technology is controlled, so it will have obvious advantages compared with other energy storage technologies. At present, many countries have begun to use hydrogen energy storage technology to store renewable energy to promote the development of renewable energy.

2.2. Photovoltaic hydrogen production system

People have been more concerned about large-scale parallel grid hydrogen production technology in recent years. Grid-connected photovoltaic hydrogen production systems can be divided into the common AC bus and the common DC bus according to the specific project scale, as shown in **Figure 1**. For DC bus hydrogen production, it is necessary to interact with the power grid through an AC/DC conversion device while building the light/storage/hydrogen DC microgrid. Studies have put forward the concept of an active photovoltaic grid-connected power generation system. Hydrogen energy is used as long-term energy storage, and the power of each module is collected, coordinated, and controlled through a DC bus, to smooth the fluctuation of photovoltaic on-grid power. The literature further designed the photovoltaic hydrogen production energy storage system and proposed a system architecture and power management strategy (PMS) based on energy conversion (DC/DC and AC/DC). The photovoltaic system is used to provide power for DC loads. When the photovoltaic power is insufficient, the grid compensates the energy, and when the photovoltaic power is surplus, the excess energy is converted. The excess energy will be used in the electrolysis of water to create hydrogen. In the future, the photovoltaic DC bus hydrogen production method is expected to be combined with BIPV and light storage direct flexible technology on the user side to form a new electric-hydrogen energy system.

In the past two years, most of the photovoltaic hydrogen production projects built in Northwest China and other areas rich in photovoltaic resources have adopted the AC bus hydrogen production method, which can not only support the operation of photovoltaic hydrogen production system with the stability of the large power grid but also improve the utilization rate of equipment and improve the overall cost of the project. However, the power generation curve and peak time of some large photovoltaic power generation provinces have undergone great changes recently in the continuous grid-connected large-scale photovoltaic power stations.

With low or even negative electricity prices, there is high energy usage and demand at night, and some grid-connected photovoltaic hydrogen production projects have a worrying profit situation.

2.3. Wind power hydrogen production system

In the countries and regions with high usage rate of wind power, grid-connected hydrogen production technology has received the attention for research. In this technical route, hydrogen production devices can provide auxiliary services for wind power grid-connected. With the recent development trend of large-scale fan and hydrogen production device and parity of offshore wind power, the power of single fan and single hydrogen production device can be better matched, and people pay more attention to the coupled hydrogen production of wind ionization network. The grid-connected hydrogen production technology of large-scale wind farms is shown in **Figure 1**. Domestic and foreign scholars have carried out theoretical and practical research. In the study of hydrogen production device arranged on the AC bus side, the literature smoothed the output power of wind generator through collaborative control and made the fan more friendly to the grid based on the parallel installation of electrolytic cell in doubler wind generator for hydrogen production. Literature based on permanent magnet synchronous generator and 10 electrolyzer units to form a wind-hydrogen coupling system, formulated switching strategy, that smooth wind farm line power fluctuations through the delayed switching strategy to avoid frequent switching of electrolyzer, which improves the service life and efficiency of the electrolyzer. In the study of hydrogen production device arranged on the DC bus side, literature studied the control model of the power flow and hydrogen flow of the electrolyzer, and carried out real-time practical test through hardware-in-the-loop simulation. On this basis, literature provides robust control against fan power fluctuation and electrolyte temperature uncertainty by adjusting the current of the electrolyzer, to improve the production efficiency and quality of hydrogen gas and improve grid-connection friendliness. However, based on the hydrogen production device, only unidirectional power regulation can be achieved. Therefore, some researchers constructs a formula that includes the hybrid system of fan, hydrogen production device, fuel cell device, super capacitor, and so on, to propose a variety of operation modes and control strategies to achieve bidirectional regulation of bus power, adapt to the fluctuating characteristics of fan output, and keep the DC bus voltage stable. However, it does not take into account the delayed response of fuel cell and electrolyzer, which may lead to short mismatch. Another study proposes an energy flow control strategy that uses fuel cells and electrolyzers as buffers to compensate or absorb the power difference between the fan and load scheduling over a long time scale [4]. In the short time scale, the supercapacitor is used as a buffer to compensate for the power imbalance caused by the delayed response of the fuel cell and electrolyzer, and to ensure that the grid-connected power is consistent with the load scheduling.

2.4. Wind-solar complementary hydrogen production system

The new energy hydrogen production system should have the ability to operate independently and interact with the power grid. In terms of theoretical and practical verification research, studies based on modeling and simulation conclude that the relevant factors affecting the efficiency of the wind-solar complementary hydrogen production system are as follows: total light radiation, wind speed, electrolytic cell temperature, and shadowing of the photovoltaic system caused by cloud cover and building occlusion. The studies proposed to build a comprehensive energy management platform for hydrogen production from new energy sources and balance the power through coordinated control, and put forward two working modes of determining hydrogen by electricity and determining electricity by hydrogen. In terms of system composition and corresponding control strategy, studies based on the DC bus structure of wind power/photovoltaic/hydrogen production/fuel cell, constructs a two-layer model of energy management and real-time control, sets the simulation duration of 24 hours and the step length of 1 second. The upper layer adopts the strategy of power balance to formulate the output plan of each unit in the system. The lower layer adopts the local decentralized adaptive model predictive control (MPC) method to realize the accurate control of each unit. Although the above-mentioned energy management and real-time cooperative control methods have passed the simulation verification, they ignore the delay problem of network communication in reality, especially in large-scale wind-wind complementary projects, where the rapid fluctuations of wind-wind output superimpose the delay of long-distance communication. The above-mentioned cooperative control strategy is difficult to ensure the stable operation of the system. In another study based on the DC bus structure of wind power/photovoltaic/hydrogen production/fuel cell/energy storage, the model predictive control (MPC) method is still adopted, setting the simulation time of 25 years and the step length of 1 hour [5]. The reference power of fuel cell and electrolyzer is generated to realize load tracking, and the difference of running power is balanced by the battery. With the addition of the energy storage system, the stable and reliable operation of the system has been guaranteed, but the hour-level step size cannot meet the requirements of real-time coordinated control.

In the construction of a wind-solar complementary hydrogen production system, adopting a DC bus structure can reduce the conversion link and avoid the problem of AC system frequency instability, which is the future development direction and the focus of academic research at the present stage. However, the DC bus structure is not feasible for large-scale application at this stage as it is limited by the development and industrialization of DC power conversion devices. Most of the large-scale wind-solar complementary hydrogen production systems in operation and under construction adopt AC bus form, and it is not realistic to configure energy storage regardless of cost. The system cannot be off the grid to maintain the stability of system frequency and voltage.

3. Summary

Hydrogen energy as a secondary energy source has the advantages of being green, pollution-free, and having abundant raw materials and various utilization methods. With the development of hydrogen production and storage technology, hydrogen energy will play a greater role in the future energy market. The improvement of fuel cell performance and the reduction of cost, as well as the construction of hydrogen refueling stations, are the main factors limiting the development of fuel cell industries, so solving these problems is the key to achieve the commercial application of fuel cells. The use of hydrogen as an energy carrier for renewable energy has been promoted worldwide, which is conducive to the collaborative development of renewable energy and hydrogen energy with broad utilization prospects. The field of hydrogen energy shows future prospects and a strong momentum of development, which will provide strong support for solving the human energy crisis and environmental pollution.

Disclosure statement

The authors declare no conflict of interest.

Reference

[1] Al-Shetwi AQ, 2022, Sustainable Development of Renewable Energy Integrated Power Sector: Trends, Environmental Impacts, and Recent Challenges. Science of the Total Environment, 2022(822): 153645.

[2] Ishaq H, Dincer I, Crawford CA, 2022, A Review on Hydrogen Production and Utilization: Challenges and Opportunities. International Journal of Hydrogen Energy, 47(62): 26238–26264.

[3] Akal D, Öztuna S, Büyükakın MK, 2020, A Review of Hydrogen Usage in Internal Combustion Engines (Gasoline-Lpg-diesel) from Combustion Performance Aspect. International Journal of Hydrogen Energy, 45(60): 35257–35268.

[4] Deng H, Chen T, Jiao DD, et al., 2020, Control Strategy for Energy Management of Hybrid Grid-Connected System of Wind and Hydrogen. High Voltage Engineering, 46(1): 99–106

[5] Torreglosa JP, Garcia P, Fernandez LM, et al., 2015, Energy Dispatching based on Predictive Controller of an Off-grid Wind Turbine/photovoltaic/hydrogen/battery Hybrid System. Renewable Energy, 74(2): 326–336.