Research on Hydrogen Energy Development under the Source-network-load-storage Integration

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Abstract. Against the backdrop of peak carbon dioxide emissions and carbon neutrality, and the construction of the new power system, China is accelerating the promotion of low-carbon energy. The source-network-load-storage integration, as an important component of the construction of the new power system, can effectively promote the consumption of new energy. As a type of energy storage, hydrogen energy plays an important role in alleviating peak shaving and smoothing the output of renewable energy. Therefore, this article starts from the importance of the hydrogen energy, evaluates the economic viability and development path, and predicts the future development based on its functional positioning.

Keywords: source-network-load-storage integration, hydrogen energy, new power system

1. INTRODUCTION

Against the backdrop of peak carbon dioxide emissions and carbon neutrality, and the construction of a new power system, China's low-carbon transformation of energy is accelerating. Clean energy sources such as wind power and solar energy will rapid develop, and the integrated development of source-network-load-storage integration is increasingly being valued as an important means to promote the development of clean energy[1-2]. In 2021, the China National Energy Administration issued the "Guiding Opinions on Promoting the Integration of Source-network-load-storage Integration and the Complementary Development of Multiple Energy Sources"[3], proposing that the source-network-load-storage integration can achieve the on-site consumption of clean energy, which helps to solve the problems of low proportion of energy development and consumption in power system, insufficient system regulation capacity, insufficient coordination of various power sources, and insufficient coordination of source, grid, and load[3].

Currently, China is in a critical period of energy transformation and the construction of a new structure in the power system. The interaction capacity of the power system need to be further strengthened, and the complementary and collaborative efforts of various power sources need to be further improved. As the continues to increase of the installed capacity of renewable energy such as wind power and solar energy[4], the intermittency, volatility, and randomness of

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power generation pose higher requirements for the power system [5], posing greater challenges to power quality [6]. The development of source-network-load-storage integration is of great significance for improving the flexible-regulation-ability of the power system. Hydrogen energy, as a flexible load regulation and energy storage function, will be more widely applied under the integrated development of source-network-load-storage integration.

Flexible regulation resources such as hydrogen production can effectively alleviate peak shaving pressure, promote the development of renewable energy, and smooth output of renewable energy [7]. At present, global developed economies such as the United States, the European Union, Japan, South Korea, and others view hydrogen energy as an important component of addressing climate change and national energy strategies. At the end of 2020, 16 countries had formulated comprehensive national hydrogen energy strategic plans, including P2X (hydrogen ammonia, methane, methanol, etc.), natural gas pipeline hydrogenation, hydrogenation infrastructure, hydrogen fuel cells Substantial financial funds and tax subsidies have been provided for the research and development of key technologies such as natural gas mixed hydrogen power generation and the construction of demonstration projects.

As for China, hydrogen energy has gradually been included in government work reports, and its position in the energy system has become increasingly prominent. More than ten provinces have identified hydrogen energy development goals in the 14th Five Year Plan. Recently, China's peak carbon dioxide emissions and carbon neutrality "1+N" policy system, the 14th “Five Year Plan”, and the 2035 long-term goal outline encourage the research and development, demonstration, and large-scale application of hydrogen energy full industry chain technology. In particular, the 14th Five Year Plan for Industrial Green Development, on December 3, has made overall arrangements for the development of hydrogen energy in the industrial sector with the highest demand for hydrogen energy. It requires the implementation of renewable energy electrolysis hydrogen production demonstration projects, the development of clean energy equipment such as high-efficiency hydrogen fuel cells, and encourages the promotion of the application of hydrogen energy in industries such as steel, cement, chemical, and refining. Therefore, this article analyzes the main role of hydrogen energy, evaluates the technological trends and economic benefits of hydrogen energy, and proposes the future development path and trend of hydrogen energy.

2. THE FUNCTIONAL OF HYDROGEN ENERGY

Hydrogen energy is mainly used as a raw material and as a fuel. As a raw material, utilizing new energy for power generation to produce green hydrogen provides hydrogen raw materials for industries such as steel, chemical, and petrochemical through technological pathways such as hydrogen metallurgy, petroleum refining, and coal chemical industry, reducing the demand for hydrogen production from fossil fuels such as coal and natural gas and carbon dioxide emissions. In terms of fuel use, the use of new energy for power generation to produce green hydrogen and further synthesize synthetic fuels such as methanol and ammonia. Through technological paths such as hydrogen fuel cell vehicles, hydrogen fuel cell cogeneration, hydrogen mixed gas turbines, hydrogen fueled gas turbines, and ammonia mixed combustion power generation, energy is provided for the industrial, construction, transportation, and power

sectors, reducing fossil energy consumption and carbon dioxide emissions such as oil, coal, and natural gas.

With technological progress, it is expected that by 2030, the cost of renewable energy hydrogen supply will decrease to 30 yuan/kg, which is half of the current hydrogen produced through the use of clean energy for power generation, as shown in Figure.1. It is on par with the current cost of hydrogen produced from fossil fuels such as natural gas, and calculated based on equivalent calorific value, it is on par with the cost of finished oil; At that time, broad hydrogen energy storage will be economically viable. It is expected to decrease to 15 yuan/kg by 2060, reaching half of the finished oil, further improving the economy of generalized hydrogen energy storage.

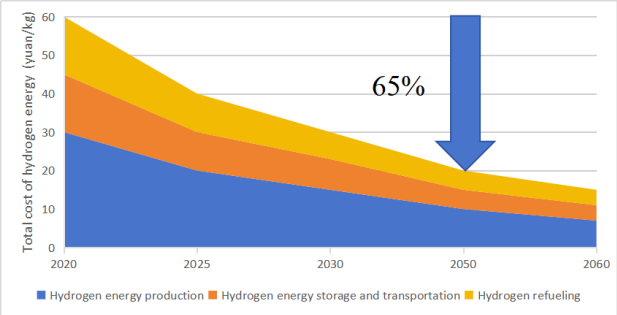

Figure.1. Trend of cost changes in various stages of hydrogen energy.

Under extreme weather conditions, the load rapidly increases and new energy continues to have low output. The power system requires long-term energy storage of at least weeks to support the balance of electricity and energy. Electrochemical energy storage, as a long-term energy storage method, will greatly increase its cost and not be economically viable. It is expected that by 2060, renewable energy electricity will be converted into hydrogen storage for a long period of time, and hydrogen will be reused for power generation when needed, and the cost of injecting it into the power system will continue to decrease to 0.62 yuan/kWh. The economy is much higher than electrochemical energy storage for the same duration, and the energy storage duration is also much longer than ordinary pumped storage.

3. Research on the Development Path of Hydrogen Energy

3.1Core-technology Innovation

The major developed economies around the world attach great importance to the development of green industries such as hydrogen energy, and have forward-looking layout of hydrogen energy core technologies. They have achieved significant first-mover advantages in the industrial chain, intellectual property rights, product lineage, and international cooperation layout, putting forward more urgent requirements for China to accelerate hydrogen energy technology innovation and industrial development.

Hydrogen energy, as the core and key technology of green and low-carbon industries, is crucial for enhancing China's strategic technological strength and seizing the global commanding heights of new energy technology and industry. China has always regarded hydrogen energy as

a strategic emerging industry. Under the framework of dual carbon development, it is necessary to accelerate the innovation and breakthrough of core technologies in various aspects such as hydrogen generation, storage and transportation, refueling, and application, promote economic structural transformation and adjustment, and support high-quality economic development.

3.2Sharing the pressure of carbon reduction in the power sector

It is expected that by 2060, China's hydrogen energy demand will reach 130 million tons, as shown in Table 1. At present, China's hydrogen energy demand is 33.42 million tons. According to the prediction of the China Hydrogen Alliance, in 2060, China's industrial sector will use 78 million tons of hydrogen, transportation sector will use 40 million tons of hydrogen, construction sector will use 6 million tons of hydrogen, and electricity sector will use 6 million tons of hydrogen.

Table 1. Hydrogen demand and carbon emission reduction contribution in various fields

	Current carbon emissions (100 million tons),	***hydrogen demand (10000 tons)***	***Reduction of carbon emissions (100 million tons)***	***Proportion of current carbon emissions (%)***
Industry	38	7800	11	28
Traffic	10	4000	4.6	40
Building	10	600	0.7	7
Power	40	600	0.7	1.8
Other	2	-	-	-
Total	100	13000	17	17

Preliminary calculations show that the development of hydrogen energy will reduce carbon dioxide emissions by 1.7 billion tons, accounting for 17% of the current total carbon dioxide emissions from energy activities in China (10 billion tons). Among them, the industrial sector has the largest total emission reduction, reaching 1.1 billion tons (accounting for 28%); The proportion of emission reduction in the transportation sector is the highest, reaching 40% (460 million tons).

Hydrogen for industrial fuels, road transportation, and building heating and power supply will replace some of the electricity demand, reducing the pressure on carbon emissions reduction in the power sector. According to preliminary calculations, 4200 tons of hydrogen energy will be used in the field of electricity substitution by 2060, replacing 1.7 trillion kilowatt hours of electricity, reducing terminal electrification rate by 7 percentage points, and reducing carbon emissions transferred to the power sector by 750 million tons, accounting for approximately 19% of the current total carbon emissions in the power sector (4 billion tons), as shown in Table 2.

Table 2. Reducing the transfer of carbon emissions from industrial, construction, and transportation hydrogen to the power sector

	Hydrogen demand (10000 tons)	***Alternative electrical energy (100 million kWh)***	***Reduction of carbon emissions (100 million tons)***
Industry	7800	7900	3.6
Traffic	4000	6400	2.9
Building	600	2400	1.1
Total		16700	7.5

3.3Promote the consumption of new energy

At the power output end, utilizing the integration model of clean energy bases and hydrogen energy industry, large-scale new energy power generation and hydrogen production will be carried out, and new energy electricity will be transported to the industrial, transportation, and construction fields in the form of hydrogen. This will broaden the channels for large-scale new energy consumption, improve the installed capacity and utilization rate of new energy, and promote the coordinated development of new energy quantity and rate. In the receiving area, utilizing distributed new energy for power generation and hydrogen production, constructing P2X, hydrogen fuel cell cogeneration, hydrogen fuel vehicle refueling, hydrogen boiler heating and other electric hydrogen coupling comprehensive energy systems, effectively utilizing distributed new energy, improving local power grid self balancing capacity, and improving power grid investment and utilization efficiency.

It is expected that by 2060, China's new energy power generation and hydrogen production will increase by 1.3-22 billion kilowatts of new energy installed capacity. In 2060, China's demand for hydrogen energy reached 80-13 million tons. According to the 80% hydrogen production ratio of new energy generation, it will consume 2.7-4.4 trillion kilowatt hours of new energy generation. According to the annual average utilization hours of 2000 hours, the newly added installed capacity of new energy is 1.3-22 billion kilowatts.

3.4Enhancing the flexible regulation capability of new power systems

In 2030, the country's demand for installed energy storage capacity will be about 200 million kilowatts. It is estimated that in 2030, the country's maximum load is 1.94 billion kilowatts. Considering 4% demand response (10.80 million kilowatts) and 13% reserve capacity (250 million kilowatts), the power balance during the evening peak hour requires about 2.11 billion kilowatts. By then, the installed capacity of new energy (wind power and solar energy) will be 1.7 billion kW, and the installed capacity of other power sources will be 2.1 billion kW. The new energy will provide 110 million kW of new energy, and other power sources will be 1.81 billion kW, with 190 million kW of power, which should be configured to meet the requirements. Based on 95% of the energy storage requirements participating in the evening peak hour power balance, the energy storage demand is 200 million kilowatts.

In 2060, the national energy storage installed capacity demand is about 600 million kilowatts, three times that of 2030.It is expected that in 2060, the country's maximum load is 2.47 billion kilowatts, considering 10%demand response (250 million kilowatts)， 13% reserve(320

million kilowatts), and the evening peak hour power balance demand is 2.54 billion kilowatts. At that time, the installed capacity of new energy reached 4.6billion kilowatts, the installed capacity of other power sources reached 1.94 billion kilowatts, according to the new energy to provide 370 million kilowatts, other power sources to provide 1.6 billion kilowatts. there is still 570 million kilowatts of power, need to configure energy storage to meet. According to 95% participation in the evening peak hour power balance calculation,energy storage demand of 600 million kilowatts.

With the advancement of hydrogen blending gas turbines, hydrogen fuel gas turbines, solid oxide fuel cells, and ammonia hybrid power generation technologies, it is becoming economically feasible for hydrogen (ammonia) in new energy generation to return to the grid in the form of electricity. The demand for hydrogen energy as energy storage and peak shaving electricity will be released.

By using electric hydrogen coupling technology to achieve electricity hydrogen electricity conversion, hydrogen energy can play a long-term energy storage role and support the balance of electricity and electricity.

At present, the coupling of electricity and hydrogen mainly involves the production of hydrogen by electricity, which only "absorbs" electricity from the power grid and does not "inject" electricity into the power grid. It only has a generalized energy storage function. At present, hydrogen energy is mainly used in industrial processes and has a small scale of application in the terminal field. In the power field, it is mainly small-scale renewable energy electricity for hydrogen production, which only "absorbs" electricity from the power grid to meet the hydrogen demand of fuel cell vehicles and other uses. Large scale electricity hydrogen bidirectional coupling has not yet been achieved, and its support for power balance during peak hours is limited.

In the long run, the coupling of electricity and hydrogen can achieve a two-way interaction between electric hydrogen production and hydrogen power generation, which can not only "ingest" from the power grid but also "inject" electrical energy. It has a narrow energy storage function and supports long-term electricity balance. The application scale of hydrogen energy in the terminal field has significantly expanded, and its application in the power field has expanded from renewable energy to hydrogen fuel cell power generation, natural gas hydrogen blending power generation, hydrogen to ammonia and coal or biomass blending power generation, providing flexible adjustment resources for the power system and supporting long-term power and electricity balance.

It is expected that by 2060, the scale of hydrogen used for hydrogen power generation in China is expected to reach 4 million to 6.5 million tons, equivalent to 0.4-0.65 billion kilowatts of pumped storage energy (with an annual utilization time of 3200 hours), as shown in Table. 3. In other words, every 100000 tons of hydrogen stored for power generation plays a supporting role in balancing electricity and electricity, equivalent to 1 million kilowatts of pumped storage energy.

Table 3. Prediction of Hydrogen Energy Demand and Hydrogen Production Electricity Consumption in 2060

	Low scenario	***Medium scenario***	***High scenario***
Hydrogen energy demand (10000 tons)	8000	10000	13000
Hydrogen production ratio by electricity (%)	80	80	80
Hydrogen production electricity consumption (kWh/kg)	42	42	42
Hydrogen production electricity consumption (trillion kilowatt hours)	2.7	3.4	4.4
Proportion in total social electricity consumption (%)	17	21.5	28

4. CONCLUSION

The coordinated development of source network load storage can effectively promote the consumption of clean energy and improve the flexible regulation ability of the power system. Hydrogen energy, as a flexible load regulator and energy storage device, will be widely used in the integrated development of "source network load storage". It is expected that by 2060, China's new energy power generation and hydrogen production will increase the installed capacity of new energy by 1.3-22 billion kilowatts. In 2060, China's demand for hydrogen energy reached 80-130 million tons. Based on the 80% proportion of hydrogen production from new energy power generation, it will consume 2.7-4.4 trillion kilowatt hours of new energy power generation. According to the annual average utilization hours of 2000 hours, the installed capacity of new energy will increase by 1.3-22 billion kilowatts. The scale of hydrogen used for hydrogen power generation in China is expected to reach 4 million to 6.5 million tons, equivalent to 0.4-0.65 billion kilowatts of pumped storage energy (with an annual utilization time of 3200 hours).

Finally, complete content and organizational editing before formatting. Please take note of the following items when proofreading spelling and grammar:

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