American Journal of Energy Engineering
2023; 11(2): 38-44
http://www.sciencepublishinggroup.com/j/ajee
doi: 10.11648/j.ajee.20231102.11
ISSN: 2329-1648 (Print); ISSN: 2329-163X (Online)

Energy Mutual Networking Establishment Method Based on Hydrogen Production from Water Electrolysis Technology

Xin Nie[1, *], Anjar Praditya Wicaksono[2]

[1]Guangdong Qingyuan China Energy Power Generation Co., Ltd., China Energy Investment, Qingyuan, China
[2]PT. Guohua Taidian Pembangkitan Jawa Bali, China Energy Investment, Serang, Indonesia

Email address:
710143100@qq.com (Xin Nie), anjarpraditya.09@gmail.com (Anjar Praditya Wicaksono)
[*]Corresponding author

To cite this article:
Xin Nie, Anjar Praditya Wicaksono. Energy Mutual Networking Establishment Method Based on Hydrogen Production from Water Electrolysis Technology. *American Journal of Energy Engineering*. Vol. 11, No. 2, 2023, pp. 38-44. doi: 10.11648/j.ajee.20231102.11

Received: March 17, 2023; **Accepted**: April 6, 2023; **Published**: April 14, 2023

Abstract: The new power system has the characteristics of a high proportion of renewable energy power generation and multi-field interconnection. In order to reduce the carbon emission level of the new power system, it is necessary to improve the flexible response capability of the system in the form of different energy carriers. Analyze the feasibility of two hydrogen energy utilization technologies such as water electrolysis for hydrogen production and carbon dioxide hydromethanation, and propose to use hydrogen as an energy carrier to form an energy mutual networking, through the transformation between renewable energy-electricity-hydrogen energy-electricity-chemical energy, the flexible response capability of the new power system can be improved, and the carbon emission level of the new power system can be reduced. The method of building the energy mutual networking on the basis of water electrolysis for hydrogen production technology is as follows: first, use renewable energy for water electrolysis for hydrogen production, and use hydrogen to supplement power generation through fuel cells when the power output is insufficient; then, capture carbon dioxide generated by thermal power generation, use hydrogen to reduce carbon dioxide to produce methane and finally, hydrogen and methane are sent to the natural gas pipeline network for reuse. At the same time, an energy storage system with an appropriate capacity is installed in the new power system to stabilize the volatility of wind-solar hybrid power generation, and the use of wind-solar hybrid energy storage power generation technology can further improve the hydrogen production efficiency of renewable energy.

Keywords: The New Power System, Water Electrolysis for Hydrogen Production, Carbon Dioxide Hydromethanation, Wind-Solar Complementary Energy Storage, Energy Mutual Networking

1. Introduction

In order to promote the reduction of greenhouse gas emissions, mainly carbon dioxide, the Chinese government has proposed the following carbon emission reduction timetable: strive to achieve "carbon peak" by 2030, achieve "carbon neutrality" by 2060, and build a new type of power system with new energy as the main body during the period of 2021 to 2025. Fossil energy accounts for about 85% of China's energy structure, it is estimated that China's carbon emissions will reach a peak of 11.6 billion tons by 2030, of which 85.4% of the carbon is produced by energy activities. In the era of "carbon peaking" and "carbon neutrality", the new power system is facing huge pressure to reduce carbon emissions, but it also breeds new opportunities and hopes.

The new power system has the characteristics of a high proportion of renewable energy power generation and multi-field interconnection. In order to reduce the carbon emission level of the new power system, it is necessary to improve the flexible response capability of the system in the form of different energy carriers. Hydrogen energy and electric energy are both secondary energy sources and the main carrier of energy. Hydrogen energy has the characteristics of high energy density, high energy conversion efficiency, and various production methods. Hydrogen energy is also a true zero-emission energy source. Therefore, exploring the use of hydrogen as an energy carrier to convert hydrogen energy into electrical energy, thermal energy, and chemical energy for comprehensive utilization is an effective means to reduce the carbon emission level of the new power system.

2. Features of the New Power System

2.1. High Proportion of Renewable Energy Generation

Table 1 is a list of China's renewable energy power generation installed capacity in 2022. As of the end of 2022, China's cumulative power generation installed capacity is 2564.05GW, of which thermal power installed capacity is 1332.39GW, renewable energy power generation installed capacity is 1209.53GW, and nuclear power generation installed capacity is 555.30GW, the installed capacity of renewable energy power generation accounted for 47.17% of the total installed capacity of power generation. It is estimated that by 2025, the installed capacity of renewable energy in China will account for more than 50% of the total installed capacity of power generation.

Table 1. *List of China's Renewable Energy Power Generation Capacity in 2022.*

Category	Power generation installed capacity/GW	Percentage of total installed power generation capacity/%
Hydropower	413.50	34.19
Wind power	365.44	30.21
Solar power	392.61	32.46
Biomass power generation	37.98	3.14

Figure 1 is a bar chart of the average utilization rate of China's major renewable energy power generation in 2022. By the end of 2022, China's renewable energy power generation capacity will be 1,062,440GW·h, of which the hydropower generation capacity above scale is 482,670GW·h, and wind power generation capacity is 344,180GW·h. Solar power generation is 157,640GW·h, biomass power generation is 77,950GW·h, abandoned water power in major river basins in China is about 5364GW·h, abandoned wind power is about 12640GW·h, and abandoned solar power is about 3320GW·h, the average utilization rate of hydropower, wind power and solar power generation are 98.9%, 96.4% and 97.9%, respectively.

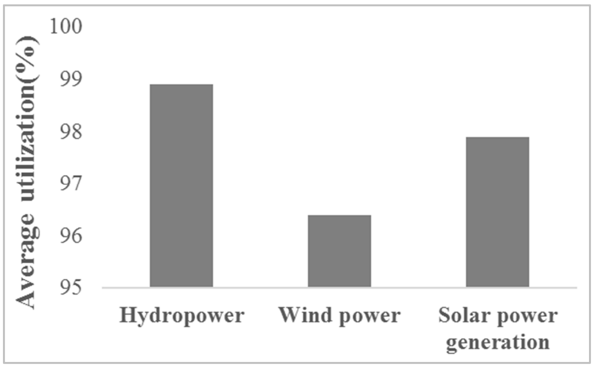

Figure 1. *Column chart of China's main renewable energy generation utilization rate in 2022.*

With the access of large-scale and high-proportion renewable energy power, due to the periodic intermittent fluctuations of renewable energy in the time dimension and the differences in resource endowment in the space dimension, there are problems of water, wind and light abandonment in the power system, thus increasing the carbon emission level of the power system. The mismatch between the development of renewable energy and the consumption capacity of the power system makes the new power system undertake complex and heavy consumption tasks, and it is necessary to improve the flexible response capability of the system in different time scales and in different forms of energy carriers [1].

2.2. Multi-Field Interconnection

The "Renewable Energy Law of the People's Republic of China (Amendment)" implemented in 2010 clearly stated that "the state implements a full guaranteed purchase system for renewable energy power generation". The problem of abandoning wind and light needs to promote the flexible adjustment capability of the system through the power supply side, grid side, demand side, and energy storage side to meet the requirements of large-scale new energy grid integration. Therefore, in the new power system, as the traditional power system's single "source follows the load" mode (that is, the power generation is adjusted according to the load change) mode is transformed into an interactive mode of "the source follows the load, and the load follows the grid". The system will be interconnected with natural gas, transportation, construction and other fields, energy nodes such as power networks, oil networks, and natural gas networks composed of distributed energy storage devices and various types of loads will be interconnected. Smart grids and heating pipeline network, natural gas pipeline network and transportation network will be interconnected to form an energy mutual networking.

3. Technical and Economic Analysis of Hydrogen Energy Utilization

3.1. Water Electrolysis for Hydrogen Production

Water electrolysis for hydrogen production is a technology that provides energy to water through electric energy and destroys the hydrogen-oxygen bond of water molecules to produce hydrogen [2]. Direct current is passed through the electrolytic cell, and water molecules undergo an electrochemical reaction on the electrodes to decompose into hydrogen and oxygen. Among them, hydrogen is generated near the cathode, and oxygen is generated near the anode. Formula 1, formula 2 and formula 3 are respectively chemical equations for cathodic, anodic, and total reactions.

Cathode: $4H_2O+4e \rightarrow 2H_2\uparrow + 4OH^-$ (1)

Anode: $4OH^- - 4e \rightarrow 2H_2O + O_2\uparrow$ (2)

Total reaction formula: $2H_2O \rightarrow 2H_2\uparrow + O_2\uparrow$ (3)

According to the different electrolytes, mainstream water electrolysis for hydrogen production technology can be divided into alkaline water electrolysis hydrogen production (AWE), proton exchange membrane water electrolysis hydrogen production (PEM) and solid oxide electrolysis cell water electrolysis hydrogen (SOEC). The working principle of the three electrolyzed water hydrogen production technologies is shown in Figure 2. At present, the high production cost is the main factor restricting the large-scale commercial application of water electrolysis for hydrogen production technology. Since electricity accounts for the largest proportion of the cost of water electrolysis for hydrogen production, there are currently two ways to reduce the cost of hydrogen production: one is to reduce the energy consumption in the process of hydrogen production, and the other is to use low-cost or low-quality electricity [3].

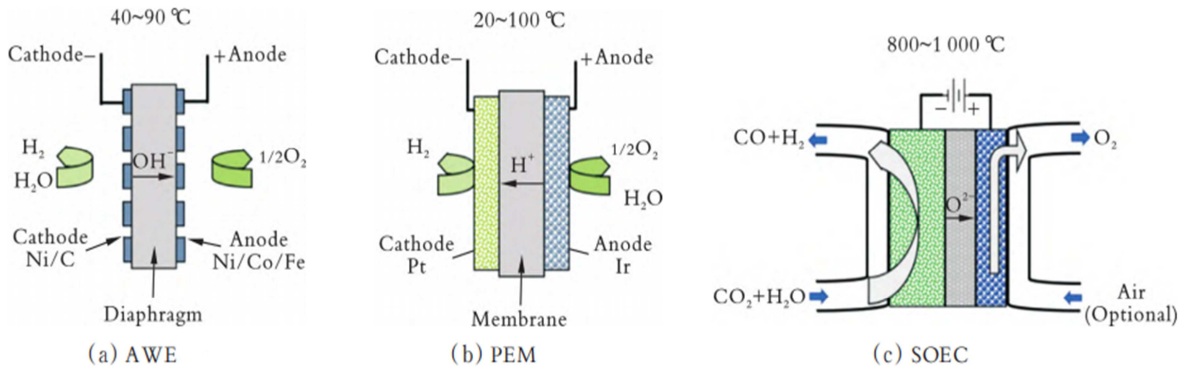

Figure 2. *Working principle diagram hydrogen production by electrolysis of water.*

3.1.1. AWE Technology

AWE is the earliest technology to realize industrialization and was applied in the early 20th century, it is the most mature and economical technology for hydrogen production by electrolytic water. AWE technology uses alkaline solutions such as KOH and NaOH as electrolytes, and uses asbestos, ceramics, nylon and other porous materials as separators, with an electrolysis temperature of 40°C-90°C and an electrolytic pressure of 1.0MPa-3.0MPa. AWE system is relatively simple, Its core device, lye electrolyzer, has a simple structure, easy to operate, and the requirements for raw material water quality are not high, the life can reach 10-20 years or even longer, and the cost advantage is obvious. However, AWE technology still has many disadvantages in engineering applications, such as low current density, poor dynamic response, Poor diaphragm sealing, and lye corrosion [4]. To solve the above problems, the researchers developed an anion exchange membrane (AEM) technology, which is expected to become an improvement of AWE technology and play a technological and cost advantage in large-scale hydrogen production. AEM technology uses an anion exchange membrane as a diaphragm, and pure water or weak lye as the electrolyte to realize OH^- transport from cathode to anode [5]. AEM technology has low cost, and the diaphragm has good air tightness, stability and low electrical resistance, and can achieve high conductivity and high current density with non-precious metal catalysts, which is a promising hydrogen production technology. The disadvantages of AEM technology are low ionic conductivity and poor high temperature stability, and further research and development of efficient and stable separators and suitable high-performance catalysts are required [6].

At present, AWE technology is mature and has been widely used. The electrolytic water hydrogen production process is simple and pollution-free, the production efficiency is generally 75%-85%, and the power consumption per cubic meter of hydrogen is 4kW·h-5kW·h. The cost of water electrolysis for hydrogen production mainly includes two parts: electricity cost and equipment cost [7]. Among them, electricity cost accounts for the largest proportion (generally 40%-80%), and the cost of electrolyzer accounts for about 40%-50% of the equipment cost.

3.1.2. PEM Technology

PEM technology uses perfluorosulfonic acid proton exchange membrane as a diaphragm. Compared with other diaphragm, proton exchange membranes have the advantages of chemical stability, high proton conductivity, non-porous gas isolation, and can be integrated with electrodes to reduce additional resistance and power loss due to the distance between the poles. Therefore, PEM technology can improve the purity of hydrogen production, while obtaining high current density and fast response, suitable for renewable energy power generation systems with high fluctuations [8]. The main disadvantage of PEM technology is its high cost. First of all, the proton exchange membrane is expensive, and the electrocatalyst used almost depends on platinum-based precious metals and their alloys, which greatly increases the equipment cost. Secondly, compared with AWE technology, PEM technology has higher requirements for water quality, which increases costs and brings difficulties to the supply of raw materials [9].

3.1.3. SOEC Technology

SOEC technology uses solid oxide as electrolytic substance, and directly ionizes water vapor to prepare H_2 and O_2 in a high temperature environment of 800°C-1000°C, which can realize the conversion of electrical and thermal energy into chemical energy. The electrolytic cell consists of porous electrodes at both ends and a dense electrolytic substance in the middle, which is used for efficient conduction of oxygen ions or protons, and porous electrodes that facilitate the rapid diffusion and transport of gases. Generally, zirconia-nickel series cermet is used as cathode material, and non-precious metals such as perovskite oxide are selected as anode materials, which have high ionic conductivity and excellent stability at high temperature [10]. The biggest advantage of SOEC technology is its high energy conversion efficiency, generally up to 85%-100%, which can effectively reduce the energy consumption required for the electrolysis process and does not require precious metal catalysts. The disadvantages of SOEC technology are that the material cost is high, the high temperature sealing is more difficult, and the high temperature and high humidity environment puts forward higher requirements for the chemical and mechanical stability of the material, which limits the development of SOEC technology to a certain extent. At present, SOEC technology is still in the laboratory research and development stage, and it cannot be commercialized in the short term [11].

3.1.4. Hydrogen Production by Direct Electrolysis of Seawater Technology

In order to reduce the cost of water electrolysis for hydrogen production, in November 2022, Academician Xie Heping of Shenzhen University published a research result entitled "A membrane-based seawater electrolysis for hydrogen generation" in "Nature". Combining such physical and mechanical processes with electrochemical reactions, a theoretical model of direct electrolytic hydrogen production from seawater driven by phase change migration was established, and the mechanism of the influence of interfacial pressure difference under the micron-scale air gap channel on the spontaneous phase change and mass transfer of seawater was established, forming an electrochemical The dynamic self-regulating and stable electrolytic hydrogen production method of reaction and seawater migration solves the technical problems of chlorine evolution side reaction, calcium and magnesium precipitation, and catalyst deactivation faced by direct electrolytic hydrogen production of seawater, and develops the in-situ direct electrolytic hydrogen production technology of seawater. The 400L/h seawater in-situ direct electrolysis hydrogen production equipment developed according to the seawater in-situ direct electrolysis hydrogen production technology has been continuously operated in Shenzhen Bay seawater for more than 3200 hours, realizing stable and large-scale hydrogen production. Seawater in-situ direct electrolysis hydrogen production technology can make full use of low-cost and low-quality offshore wind power, and combine it with offshore renewable energy to build an integrated in-situ seawater hydrogen production plant, which can effectively reduce the production cost of water electrolysis for hydrogen production [12].

3.2. Carbon Dioxide Hydromethanation

3.2.1. Technical Principles

Carbon dioxide hydromethanation is a theory proposed by French chemist Paul Sabatier in 1902. Methanation reaction is the reaction of reducing carbon monoxide and carbon dioxide with hydrogen to generate methane and water in the presence of a catalyst. Hydromethanation of carbon dioxide is a process of reducing carbon dioxide with hydrogen. It is also one of the practical and effective technologies in the recycling of carbon dioxide [13]. Pass a certain proportion of carbon dioxide and hydrogen through a reactor equipped with a catalyst, and under certain temperature and pressure conditions, carbon dioxide and hydrogen react to form water and methane [14].

$$CO_2 + 4H_2 \rightarrow CH_4 + 2H_2O \qquad (4)$$

Equation 4 is the Hydromethanation reaction formula. Since the carbon dioxide hydromethanation reaction is a strongly exothermic reversible reaction, once the reaction starts, it will quickly reach equilibrium. Therefore, the temperature controlled in actual production should take into account both the reaction speed and the chemical balance. Figure 3 is a schematic diagram of the reaction mechanism of carbon dioxide hydromethanation. Carbon dioxide is converted into adsorbed formate and carbonate on the surface of the catalyst, and then reacts with hydrogen to further convert into methane [15].

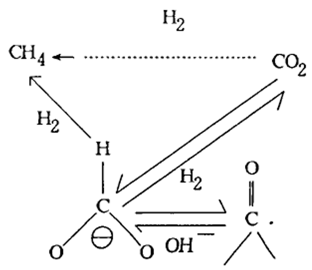

Figure 3. *Reaction mechanism diagram of carbon dioxide hydrogenation methanation.*

3.2.2. Technological Development Constraints and Solutions

Carbon dioxide is a "carbon source" compound that exists in large quantities in nature. China has industrialized the technology of producing methane and methanol through the direct carbon dioxide hydrogenation reaction of coal-to-gas, and it is feasible to promote carbon dioxide hydrogenation methanation technology. The problem is that the cost of carbon capture (CCS) in exhaust gas is still very high, therefore, the carbon capture link is the main factor restricting the promotion of carbon dioxide hydromethanation technology [16]. In view of the high cost of CCS, Fang Mengxiang's research team of Zhejiang University proposed a low-energy consumption chemical absorption carbon capture technology in 2022, which mainly includes high-efficiency, low-degradation composite amine absorber, low-energy phase change organic amine and non-aqueous absorber formulation, which reduces the energy consumption of carbon capture by more than 30% compared with traditional monoethanolamide absorber. At the same time, it has also invented reinforced equipment such as microstructure hydrophilic modified plastic packing tower, micro-nano surface composite corrugated plate, high-efficiency plate heat exchanger and high-efficiency falling film boiling apparatus, which greatly reduces the process investment of carbon capture. The chemical absorption carbon capture technology with low energy consumption has been applied in the 150,000 tons/year coal-fired power plant chemical absorption CO_2 capture demonstration project of China Energy Investment.

4. Use Hydrogen as an Energy Carrier to form an Energy Mutual Networking

4.1. Establishment Method

Figure 4 is a schematic diagram of the structure of the energy mutual networking with hydrogen as the energy carrier. The electricity produced by solar energy, wind energy and other renewable energy is connected to the grid through the access point, and part of the electricity is sent to the electrolyzer to produce hydrogen and oxygen by electrolyzing water, the hydrogen is stored in the hydrogen storage equipment, and the oxygen is comprehensively utilized. When the power output is insufficient, the stored hydrogen is sent to the power grid through fuel cell power generation. On the thermal power generation side including fossil energy such as coal and natural gas, the carbon dioxide generated during the power generation process is captured, and the hydrogen produced by the electrolyzer is combined with the captured carbon dioxide. Carbon dioxide is methanated to produce methane; this methane, along with hydrogen from the electrolyzer, is sent to the natural gas pipeline network for reuse.

In the new power system, hydrogen is used as an energy carrier to form an energy mutual networking. The use of surplus, off-peak or low-quality renewable energy can reduce the cost of water electrolysis for hydrogen production, and the supplementary power generation of hydrogen fuel cells will contribute to the grid, it plays the role of peak shaving and valley filling. Through the transformation between renewable energy-electric energy-hydrogen energy-electric energy-chemical energy, it can improve energy utilization efficiency, solve the problem of renewable energy consumption, and improve the flexible response capability of the system, reduce system carbon emissions.

4.2. Technological Development Constraints and Solutions

It should be pointed out that hydrogen mixing in natural gas will have varying degrees of influence on the existing natural gas pipeline transmission system and terminal gas units. Different hydrogen mixing ratio will lead to changes in combustion velocity, heat load coefficient and other combustion indices of gas, as well as hydraulic indices such as relative density, heat transfer coefficient and viscosity. Due to different calorific value, the running state of back-end gas equipment is unstable, which is easy to increase the concentration of hydrogen and increase the risk of hydrogen corrosion in the delivery system. In 2022, Baoji Petroleum Steel Pipe Co., LTD., has produced spiral hydrogen-doped welded pipes with good hydrogen brittle-resistance performance and straight seam welded pipes for pure hydrogen transport, the Baotou-Linhe hydrogen doped pipeline project, which was recently started, adopted the spiral hydrogen doped welded pipe with diameter of 457mm and wall thickness of 8.8mm.

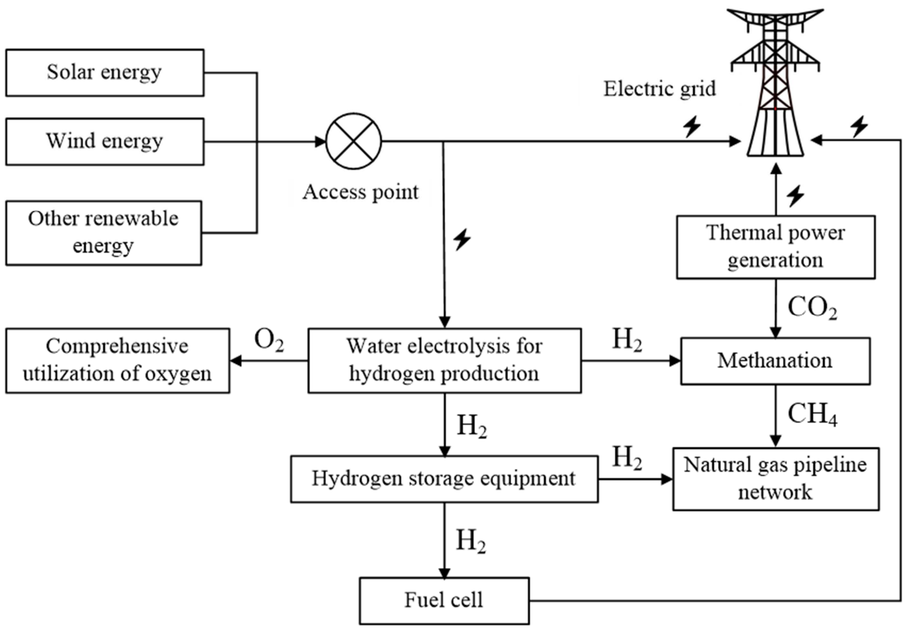

Figure 4. *Schematic diagram of the structure of the energy mutual networking with hydrogen as the energy carrier.*

4.3. Ways to Improve the Efficiency of Hydrogen Production from Renewable Energy Sources

To use renewable energy to generate water electrolysis for hydrogen production, it is necessary to configure an energy storage system with an appropriate capacity to stabilize the fluctuation of wind-solar hybrid power generation and improve the efficiency of hydrogen production. The wind-solar hybrid energy storage power generation hydrogen production system is mainly composed of wind turbines, solar photovoltaic cells, controllers, energy storage devices, inverters, electrolyzers, etc. The specific process is that the DC power from the photovoltaic array and wind turbines passes through the controller stores excess energy in the energy storage device, and then converts it into alternating current through the inverter, which is used to water electrolysis for hydrogen production. Figure 5 is a diagram of the hydrogen production system for wind-solar hybrid energy storage power generation. In the new power system, an energy storage system with an appropriate capacity can be configured to stabilize the volatility of wind-solar hybrid power generation, and the use of wind-solar hybrid energy storage power generation technology can further improve the hydrogen production efficiency of renewable energy.

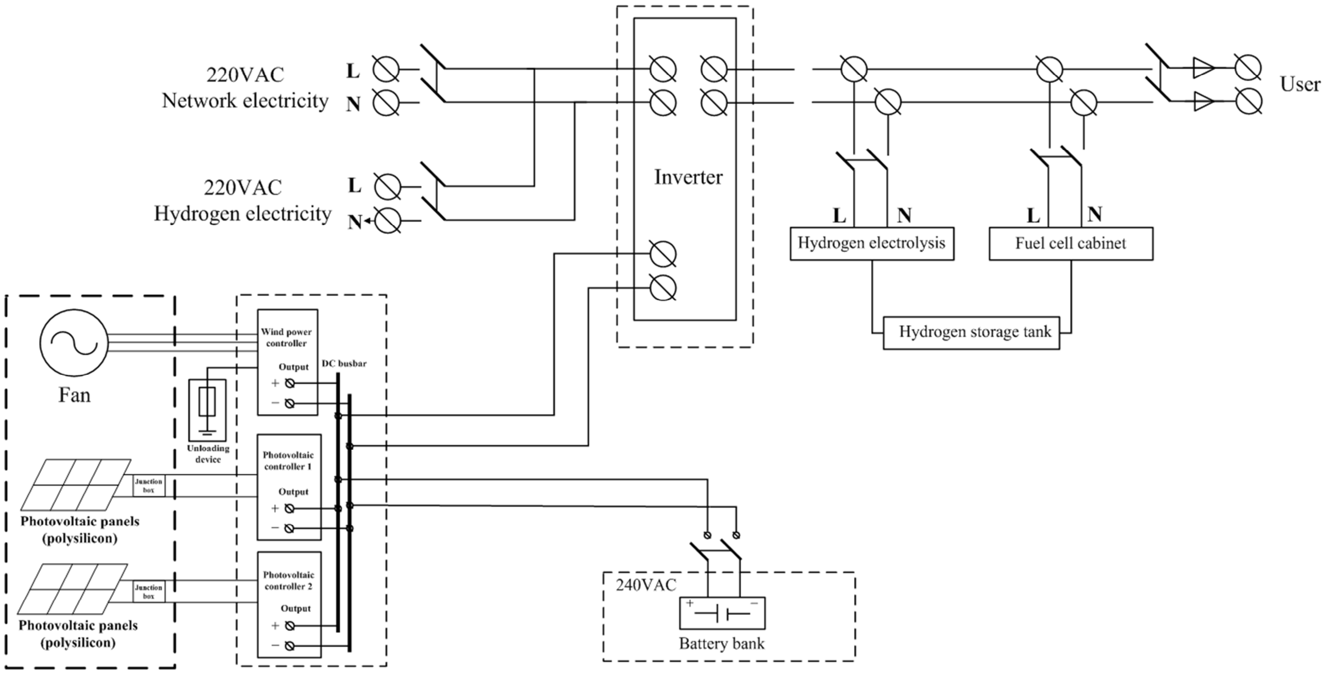

Figure 5. *Diagram of hydrogen production system of wind-solar complementary energy storage power generation.*

5. Conclusion

Water electrolysis for hydrogen production has the technical characteristics of simple process and no pollution, but the high production cost restricts the large-scale application of hydrogen production technology by electrolysis of water. The use of low-cost or low-quality renewable energy can reduce the production cost of hydrogen production. Carbon dioxide hydromethanation technology uses hydrogen produced by electrolysis of water to reduce carbon dioxide to produce methane, which can realize the recycling and reuse of carbon dioxide.

Hydrogen is used as an energy carrier, through the transformation between renewable energy-electricity-hydrogen energy-electricity-chemical energy, the flexible response capability of the new power system can be improved, and the carbon emission level of the new power system can be reduced. The method of building the energy mutual networking on the basis of electrolytic water hydrogen production technology is as follows: first, use renewable energy to electrolyze water to produce hydrogen, and use hydrogen to supplement power generation through fuel cells when the power output is insufficient; then, capture carbon dioxide generated by thermal power generation, use hydrogen to reduce carbon dioxide to produce methane; finally, send hydrogen and methane to the natural gas pipeline network for reuse.

In the new power system, an energy storage system with an appropriate capacity can stabilize the fluctuation of wind-solar hybrid power generation, and the use of wind-solar hybrid energy storage power generation technology can further improve the hydrogen production efficiency of renewable energy.

Acknowledgements

In the era of "carbon peak" and "carbon neutral", China Energy Investment is committed to green and low-carbon development. We would like to express our deep respect to China Energy Investment that has cultivated our growth.

References

[1] Zhang Yunzhou, zhang Ning, Dai Hongcai, et al. Model construction and pathways of low-carbon transition of China's power system [J]. Electric Power, 2021, 54 (3): 1-11.

[2] Cao Fan, Chen Kunyang, Guo Tingting, et al. Research on the technology path of hydrogen energy industry development [J]. Distributed Energy, 2020, 5 (1): 1-8.

[3] Wang Yuwei, Lu Haiyong, Sun Peifeng, et al. Research on the configuration and economy of new energy hydrogen production [J]. Electric Power and Energy, 2020, 41 (5): 610-613, 631.

[4] Guo changqing, Yi liqi, Yan changfeng, et al. Optimization of solar photovoltaic-PEM water electrolysis direct coupling system for hydrogen production [J]. Progress in New Energy, 2019, 7 (3): 287-294.

[5] Han Shuqi, Li Wenxin, Chen Chong, et al. Modeling and control of controllable direct-drive permanent magnet wind turbine based on wind power hydrogen production and super capacitor hybrid energy storage [J]. Guangdong Electric Power, 2019, 32 (5): 1-12.

[6] Guo Mengjie, Yan Zheng, Zhou Yun, et al. Optimal operation of integrated energy system with wind power hydrogen production device [J]. China Electric Power, 2020, 53 (1): 115-123, 161.

[7] Zhang Li, Chen Shuoyi. Development status and countermeasures of wind power hydrogen production technology at home and abroad [J]. Science and Technology China, 2020 (1): 13-16.

[8] Jiang Kangle. Research and environmental benefit evaluation of wind-solar hybrid hydrogen production system [D]. Handan: Hebei University of Engineering, 2018.

[9] Bai Shuhua. Application research of the wind solar hydrogen consociation type independent generates system [D]. Chongqing: Chongqing University, 2007.

[10] Li Wenlei. Research on hydrogen production system of wind-solar complementary power generation [D]. Handan: Hebei University of Engineering, 2019.

[11] Li Jianqiang, Yu Guangzheng, Tang Bo, et al. Multi-energy flow integrated energy system planning considering wind and solar utilization and containing hydrogen energy flow [J]. Power System Protection and Control, 2021, 49 (14): 11-20.

[12] Nie Congying, Shen Xiaojun, Lu Hong, et al. Capacity configuration and control strategy of hydrogen super hybrid energy storage in grid connected wind farm [J]. Smart Power, 2020, 48 (9): 1-8.

[13] Xu Jing, Zhao Xia, Luo Yinghong. Improved virtual synchronous generator control for hydrogen fuel cell integration into a microgrid [J]. Power System Protection and Control, 2020, 48 (22): 165-172.

[14] Lu Yifei, Chen Chong, Liang Lizhong. Modeling and control of wind-hydrogen coupling system based on electricity-hydrogen hybrid energy storage [J]. Smart Power, 2020, 48 (3): 7-14.

[15] Guo Hao, Yang Honghai. Current status and future prospect of research on solid-state hydrogen storage material [J]. New Chemical Materials, 2016, 44 (9): 19-21.

[16] Li Haibo, Pan Zhiming, Huang Yaowen. Analysis on the application prospect of hydrogen fuel gas turbine power generation [J]. Electric Power Equipment Management, 2020 (8): 94-96.