Application Direction and Prospect of Power To Gas in Methanation Process

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Abstract. The former comprises of a hydrogen comprehensive usage system, a 10MW electrolytic water hydrogen production system, and a 200MW wind farm. 17.52 million Nm3 of hydrogen may be produced annually by the project, some of which is used for industrial production to cut down on the use of fossil fuels in the industrial hydrogen production sector. A portion of it will be delivered to the hydrogen refueling station that supports the hydrogen-powered vehicle industry. The later wind farm, solar power plant, and electrolytic water hydrogen production system have respective capacities of 106 MW, 2 MW, and 4 MW. The hydrogen produced will be sent to the hydrogen refueling station via the pipeline network for use in fuel cell buses. This technology has low cost of large-scale transportation and is of great significance to mitigate CO2. Power-to-gas provides a new technical approach for fully utilizing renewable energy and improving natural gas supply capacity, with important engineering application value. This paper also describes the Power-to-gas energy storage technology. A variety of hydrocarbon fuels can be prepared by CO2 hydrogenation reaction, among which the catalyst technology for CO2 hydrogenation to methane is relatively mature, thus making the electricity-to-methane energy storage technology a practical potential electricity-to-hydrocarbon fuel energy storage technology. This paper comprehensively analyses the development status of the involved key technologies, including water electrolysis and CO2 methanation.

Keywords: P2G, Gas and electricity integrated system, methanation.

1. Introduction

With the significant progress in technology and scale of wind power and photovoltaic power generation in recent years, renewable energy is accelerating the pace of becoming the dominant energy. The large-scale development of the renewable energy industry will not only provide new growth momentum for global economic growth, but also provide a strong guarantee for ecological protection and energy supply. However, due to the intermittent and fluctuating characteristics of solar energy and wind energy, the output of renewable energy power is discontinuous, unstable and uncontrollable, and its large-scale grid connection will bring huge impacts on power quality and the safe and stable operation of the power system. This has become the main technical obstacle restricting its development. An obvious decision to support the growth of the renewable energy industry is to develop grid storage equipment that will improve the adjustable and controllable qualities of renewable energy. The number and magnitude of data centers have rapidly increased as a result of the deep integration of digital technologies like the Internet, cloud computing, big data, and artificial intelligence with traditional industries. The issues of high consumption of electricity and carbon greenhouse gases have also received considerable attention [1-3]. It is predicted that by 2035, the total power consumption of my country's data centers and 5G will reach 695.1-782 billion kW h, which is 2.5-3 times that of 2020, accounting for 5%-7% of the electricity consumption of the whole society. At the same time, the total carbon emissions of data centers and 5G will reach 230 million to 310 million tons, accounting for 2% to 4% of China's carbon emissions. Among them, the carbon emissions of data centers will increase by up to 103% compared with 2020 [4]. Therefore, studying the low-carbon optimal scheduling problem of data center source-load coordination, optimizing the allocation of various resources such as the power supply side and load side, and realizing the low-carbon and green development of the data center are crucial to the realization of "carbon peak" and "carbon neutrality". and "Double Carbon Goals" have a positive effect. In addition, many scholars have analyzed the application prospects and effects of P2G systems in multi-energy interconnection

systems. Utilizing the P2G system can minimize carbon dioxide emissions and promote environmental benefits; increase the renewable energy sources' capacity for energy absorption; combine gas turbines to achieve peak-shaving and valley-filling of the power system; use electricity-gas energy conversion to lessen the obstruction of power transmission and gas pipelines; and use The coordination and complementarity of several energy sources can increase the dependability of the electricity, gas, and heating systems. The above analysis is mostly based on the assumption that the energy conversion efficiency of the P2G system is constant. In fact, the efficiency of the energy conversion of the P2G system through internal electrolysis of water, methanation and other devices is closely related to the operating conditions and does not always remain constant. Ignoring the change of P2G system conversion efficiency with operating conditions may lead to inaccurate P2G system scheduling and planning results. Energy conversion equipment, such as gas CHP units and P2G equipment, has the advantages of high operating efficiency, fast response to backup demand, and low carbon emissions. In practical applications, it can realize the coupling of different energy sources in production, supply, and distribution. Among them, the development of P2G technology is particularly rapid. The P2G technology realizes the consumption of excess wind power in the system through the chemical reaction of electrolytic methane, realizes the energy conversion from electric energy to natural gas, and promotes the closed-loop system operation of the gas-electricity integrated energy system. In addition, P2G has the advantages of large energy storage capacity and long time. Therefore, P2G technology has become the technical support for comprehensively promoting the comprehensive energy system and large-scale consumption of wind power. Because it is in the development stage, the operating cost of P2G equipment is relatively high, and the conversion efficiency is about 50%, therefore, P2G technology has not been widely applied in the comprehensive energy system. Currently in the environment of China's power market reform, the role of P2G technology in the gas-electric comprehensive energy system will become more and more obvious. Therefore, this paper describes the main process of P2G and methanation unit.

2. Development Status of P2GSection Headings

P2G technology is mainly divided into P2H and P2M. In a broad sense, it also includes the process of further synthesizing industrial raw materials such as methanol and formic acid. The core equipment of P2H is the electrolyzer, which can be divided into three types: Alkaline Electrolyzer (AEC), Proton Exchange Membrane Electrolyzer (PEMEC) and Solid Oxide Electrolyzer (SOEC). type. The first two types belong to low-temperature electrolysis, which has been applied in engineering applications at the megawatt level. The last type belongs to high-temperature electrolysis, and the demonstration scale is still at the kilowatt level [5]. Among them, PEMEC has high hydrogen production efficiency and a fast dynamic response rate and has the strongest ability to cooperate with renewable energy with rapid fluctuation characteristics.

P2G also includes methanation technology, which can be divided into biological methanation (Biological Methanation, BM) under normal temperature and pressure conditions and catalytic methanation (Catalytic Methanation, CM) under high temperature and pressure conditions [6]. BM is often used in biogas production, which is divided into acetic acid fermentation type and hydrogen nutrition type. The reaction temperature and pressure are moderate, and the requirements for the purity of raw material gas are low, but the mass transfer capacity is poor and the reaction rate is slow. The most common reactor type is a continuous stirred tank reaction. Reactor (Continous Stirred-Tank Reactor, CSTR). In contrast, CM is more suitable for large-scale production. This paper also mainly analyzes this type of reactor, which can be further divided into a fixed-bed reactor (Fixed-Bed Reactor, FBR), two-phase fluidized-bed reactor (Two-Phase Fluidized-Bed Reactor, TPFBR), structured reactor (Constructed Reactor, CR) and three-phase reactor (Three-Phase Reactor, TPR). The first three types are gas-solid two-phase reactors, and the last type is gas-liquid-solid three-phase reactors [7]. Among them, nickel-based fixed-bed reactors are low in cost and widely used, and have the characteristics of fast reaction rate, good selectivity and high conversion rate.

Since 2012, the number of P2G demonstration projects in Europe has increased dramatically. By the end of 2018, the European, it can be counted that 35 P2G projects have been put into operation, 10 are under construction, and 18 are planned. The capacity of a single P2G project ranges from dozens of kW to several MW, and the total capacity has exceeded 30MW, of which about 60% are P2H types, about 25% are P2M types, and about 15% are the combination of P2H and P2M types. Hydrogen and methane may be injected into the gas network for storage and transfer, or used as vehicle fuel for transportation systems, or used as raw materials for industrial production, or used for combined heat and power generation to generate heat. Germany is a representative country promoting the development of P2G technology. According to statistics, 19 P2G projects have been put into operation, 5 projects are under construction, and 9 projects are planned. The number of P2G projects in Denmark and the United Kingdom is closely behind. The Werlte project in Germany is the largest power-to-methane P2G project put into operation so far, with a capacity of 6.3 MW. It uses the surplus electric energy of the North Sea offshore wind farm and carbon dioxide provided by nearby industrial enterprises to synthesize methane for the use of Audi A3 fuel vehicles.

The research on P2G technology in our country is still in its infancy, and the demonstration projects are carried out at the national level, focusing on the energy efficiency of the new cold industry, and the application economy of P2G technology has not yet been tested. Domestic P2G project type network storage and transshipment, or as a vehicle fuel for transportation systems, or as a raw material for industrial production, or for combined heat and power generation to generate heat. Germany is a representative country promoting the development of P2G technology. According to statistics, 19 P2G projects have been put into operation, 5 projects are under construction, and 9 projects are planned. The number of P2G projects in Denmark and the United Kingdom is closely behind. The Werlte project in Germany is the largest power-to-methane P2G project put into operation so far, with a capacity of 6.3 MW. It uses the surplus electric energy of the North Sea offshore wind farm and carbon dioxide provided by nearby industrial enterprises to synthesize methane for the use of Audi A3 fuel vehicles.

The Chinese research on P2G technology is still in its infancy. Demonstration projects are carried out at the national level, focusing on the hydrogen production industry and energy storage utility, and the application economy of P2G technology has not been considered. The types of domestic P2G projects are all P2H, and the most representative ones are the Hebei Guyuan wind power hydrogen production project and the Chong li wind-solar coupling hydrogen production project. The former comprises of a hydrogen comprehensive usage system, a 10MW electrolytic water hydrogen production system, and a 200MW wind farm. 17.52 million Nm3 of hydrogen may be produced annually by the project, some of which is used for industrial production to cut down on the use of fossil fuels in the industrial hydrogen production sector. A portion of it will be delivered to the hydrogen refueling station that supports the hydrogen-powered vehicle industry. The later wind farm, solar power plant, and electrolytic water hydrogen production system have respective capacities of 106 MW, 2 MW, and 4 MW. The hydrogen produced will be sent to the hydrogen refueling station via the pipeline network for use in fuel cell buses. The above two demonstration projects will accumulate valuable experience for the large-scale application of P2G systems in my country's future energy systems.

3. Development Status of P2G Section Headings

3.1. Sub heading

At present, there are three main technical routes for electricity-based hydrocarbon fuel energy storage technology (as shown in Figure 1): electrolytic water hydrogen production combined with CO2 hydrogenation technology route, electrochemical CO2 reduction technology route, and high-temperature co-electrolysis of H2O/CO2 mixed gas technology Route [8]. The technical route of hydrogen production by electrolysis of water combined with CO2 hydrogenation first uses electric energy to decompose water into hydrogen and oxygen and then reacts hydrogen and CO2 under

certain reaction conditions and the action of a catalyst to generate hydrocarbon fuels such as methane and methanol. The main technologies involved in this route (electrolyzed water technology and CO2 catalytic hydrogenation technology) are relatively mature, and several sets of demonstration devices have been built and operated around the world [9]. CO2 is reduced on the cathode of the electrolytic cell, and molecules such as CO, methanol, and formic acid can be generated according to the difference between the electrocatalyst and the electrolyte. Due to the constraints of low activity, poor selectivity and low stability of electrocatalysts, as well as the very limited dissolution and diffusion of CO2 in the electrolyte, this route is still mainly in the stage of laboratory basic research and is far from practical application. There is still a considerable gap [10]. High-temperature co-electrolysis of H2O/CO2 mixed gas technology route uses a high-temperature solid oxide electrolytic cell to co-electrolyze water vapor and CO2 at the cathode to produce synthesis gas (H2+CO), and then use the synthesis gas to produce various hydrocarbon fuels. This route has the characteristics of high energy conversion efficiency in principle, but the high-temperature solid oxide electrolytic cell technology is still immature, and various key materials (such as electrode materials, Key technical issues such as electrolyte materials and sealing materials, etc.) and improving the thermal cycle stability of the stack need to be solved urgently. In comparison, the technical route of hydrogen production by electrolysis of water combined with CO2 hydrogenation is currently the most applicable technical route for electrical hydrocarbon fuel energy storage.

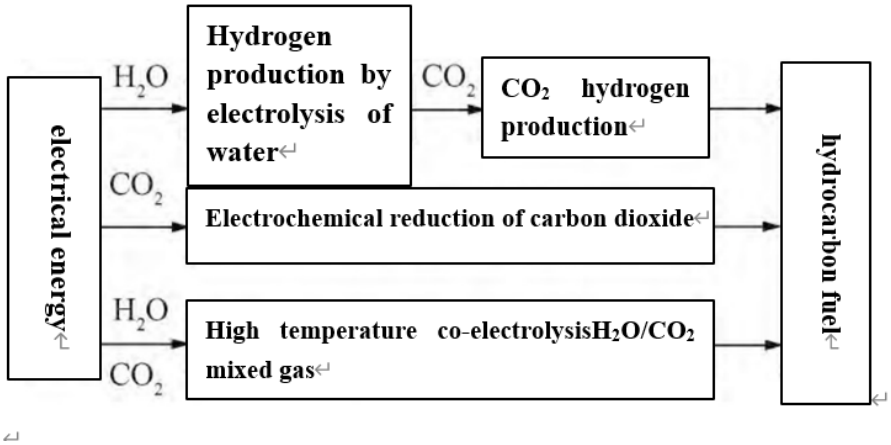


Fig. 1 Main technical route of electricity-based hydrocarbon fuel energy storage technology

In the technical route of electrolysis of water and CO2 hydrogenation, the products of CO2 catalytic hydrogenation reaction are greatly affected by the reaction conditions. Under the conditions of different catalysts, different reaction temperatures and pressures, and different ratios of CO2/H2, CO2 can undergo reduction reactions with hydrogen to different degrees to produce different products such as methane, methanol and CO. Catalysts are the key to achieving high yields of specific products.

Currently, the CO2 methanation reaction can achieve more than 95% CO2 conversion and nearly 100% methane selectivity through Ni-based catalysts at relatively low temperature and pressure [11]. Its reaction formula is (1):

$$CO_2+4H_2 \rightarrow CH_4+2H_2O \quad (1)$$

3.2. Power-to-methane energy storage technology

Electro-to-methane energy storage technology is an energy storage technology that decomposes water into oxygen and hydrogen through electrolysis, then reacts hydrogen and CO2 to synthesize methane, and stores and transports electrical energy in the form of chemical energy (as shown in Figure 2). A series of key technologies such as hydrogen production technology, CO2 methanation technology, CO2 capture technology and hydrogen storage technology are coupled.

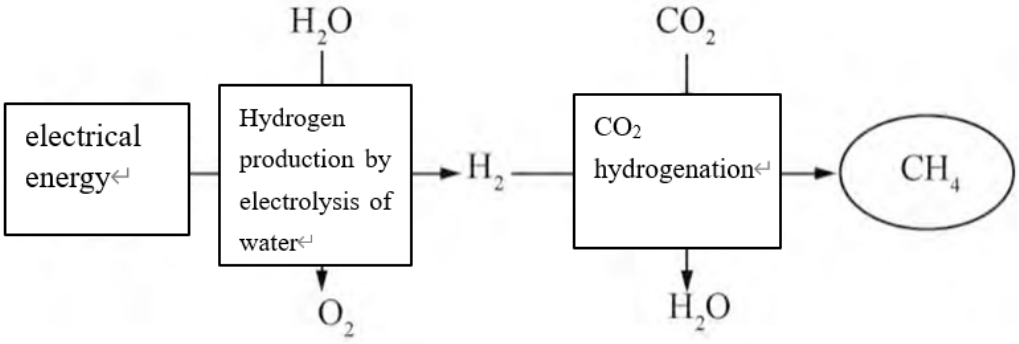


Fig.2 Power-to-methane technology4. Refined Modeling of Power-to-Gas System

In this study, the power-to-gas system can make full use of multiple. The remaining power generation resources can also make up for the shortage of power generation resources.One way is that under the premise of excess electric energy, the water passes through the electrolyzer to Decompose hydrogen to produce hydrogen, and store it through the hydrogen storage tank, and then combines recovered CO2 to produce CH4 fuel; another way is under the premise of insufficient energy, the fuel cell converts the learning energy is converted into electrical energy for power supply.

Factors such as the configuration ratio of hydrogen, the composition of syngas, the pressure value and temperature value of the chemical reaction will affect the efficiency of the chemical reaction in the process of hydrogen methanation. Therefore, this study adopts the formula (2) Methane Reactor Model.

$$P_s^{M,g}(t) = (\eta_m) E_s^{M,H_2(t)\ H_\xi \times 4} / (\Upsilon) \quad (2)$$

In the formula, $P_s^{M,g}$（t）represents the natural gas power generated by the methane reactor under the scenario of s in the period t; η_m represents the operating efficiency; H_l represents the lower calorific value of methane; $)E_s^{M,\ H2}$ represents the molar mass conversion coefficient when hydrogen is synthesized into natural gas; ϒ represents the mass of natural gas per cubic meter under standard conditions.

4. Conclusion

In the context of the energy meltdown and environmental degradation, it is now essential to connect large-scale clean energy through a gas-electricity integrated energy grid in order to achieve the renewable energy value chain. As a result of the widespread willingness to participate of wind power in the dispatching of the gas-power integrated energy system, the supply side of clean energy has grown into an important strategy for fixing the present issues. This interconnects sizable clean energy through the gas-power interconnected energy system. P2G equipment provides a wide range of benefits, including flexible gas-to-electricity energy conversion, powerful carbon capture, and low cost capacity backup, which can effectively support the best performance of the gas-to-electricity integrated energy system when wind power is connected. Using this information as a foundation, the paper thoroughly examines the non - linear and nonoptimal work schedules and thorough benefit evaluation of P2G participating in the gas-power integrated energy system under the uncertainty of wind power, in order to promote the advancement of China's gas-power interconnected energy system. The development of energy storage technology is crucial to the widespread adoption of renewable energy. Although China's energy sector is undergoing a low-carbon revolution, it will take some time to fundamentally alter the country's petroleum industrial structure. Power-to-methane energy storage technology can not only make full use of renewable energy power, but also convert CO2 produced by fossil fuel combustion into fuel for reuse. external dependence on resources. The process of CO2 hydrogenation to methane can be completed by gas-solid heterogeneous catalytic reaction or by biological method. Although the biological method has the advantages of mild reaction conditions

and high tolerance to raw gas impurities, its reaction rate is slow, mass transfer resistance is large, and the flexibility of process control is not good. Power-to-methane energy storage cloud computing application value will progressively be made clear as the scope of renewable energy power consumption expands, as will the demand for large-capacity, long-period energy storage technology. The economics and efficiency of the power-to-methane energy storage technology must be quickly enhanced, and there is still much space for advancement in all key technical links at this point. Power-to-gas technology will be a key energy storage technology in the future because it plays a significant role in reducing power peak demand and increasing the rate at which renewable energy is consumed. It can be preserved for a long time all year round and has strong scale adaptation, flexible and various terminal uses. Because of its various advantages, it will be essential in advancing China's energy transition and climatic development.

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