Power to Methane Technology for Energy Storage

Hanze Dong[1, †], Haoyu Liu[2, †], Sihan Liu[3, *, †]

[1] Department of environmental science and Engineering, Qilu University of Technology, Jinan 250358, China

[2] Detroit green technology institute, Hubei University of technology, Wuhan 430068, China

[3] School of Environmental and Chemical Engineering, Shanghai University, Shanghai 200444, China

* Corresponding Author Email: sihanliu@shu.edu.cn

†These authors contributed equally.

Abstract. Power to gas (P2G) is a technology that converts electricity into gases like H_2 and O_2 and is expected to meet future high-capacity energy storage needs. In this paper, we present an electric-gas system coupled with electricity and gas as well as an operational analysis to solve the energy dispatch problem in P2G technology. This paper introduces the principle of P2G technology and analyzes the advantages as well as the disadvantages of the technology. P2G technology allows for long-term, seasonal energy storage and a large amount of energy storage. However, the technology has low conversion efficiency and the risk of methane leakage when applied. A coupled electric-gas system consisting of gas-fired units and P2G facilities converts rich electricity into methane for transportation and transient storage with natural gas pipeline. Besides, natural gas power generation is economical and environmentally friendly, and the gas generator sets are responsive, which can better deepen the coupling between the power system and the natural gas system in the framework of the energy internet. This paper illustrates with examples that the P2G coupling technology has a good application prospect, and it has some implications for the future application of P2G technology.

Keywords: power to gas, power to methane, energy storage, renewable energy, energy internet.

1. Introduction

Currently, energy storage technology is a popular research area both internationally and domestically. There is seasonal unevenness and surplus of electricity from all types of renewable energy plants, which can lead to wastage and seasonal shortage of electricity resources. P2G technology can convert electrical energy into gases like H2 and O2,which have high energy density [1-2]. And the power to methane (P2M) technology mainly includes electrolysis of water and methanation reaction, and the technology principle are shown in Fig. 1. Electrolysis of water produces hydrogen and oxygen, which are then added to carbon sources such as CO2 and CO to synthesize methane gas that can be stored more easily than electricity. After methane is transported by pipeline, there are three main storage methods: above-ground storage equipment, natural gas pipeline storage and geological storage [3]. This technology could convert and store electricity during periods of renewable energy surplus, and burn methane through gas-fired generators to generate electricity for energy supply during power shortages, thereby increasing the system's renewable energy consumption capacity [4]. In addition, in combination with carbon capture and storage (CCS), which can capture the CO2 produced by the system itself during the power generation phase for reuse while consuming the greenhouse gas CO2 from outside the system, achieving carbon neutrality [5-6]. Combined with carbon capture technology, P2G technology can achieve long-term, high-volume energy storage and has the opportunity to be one of the effective solutions to future energy problems.

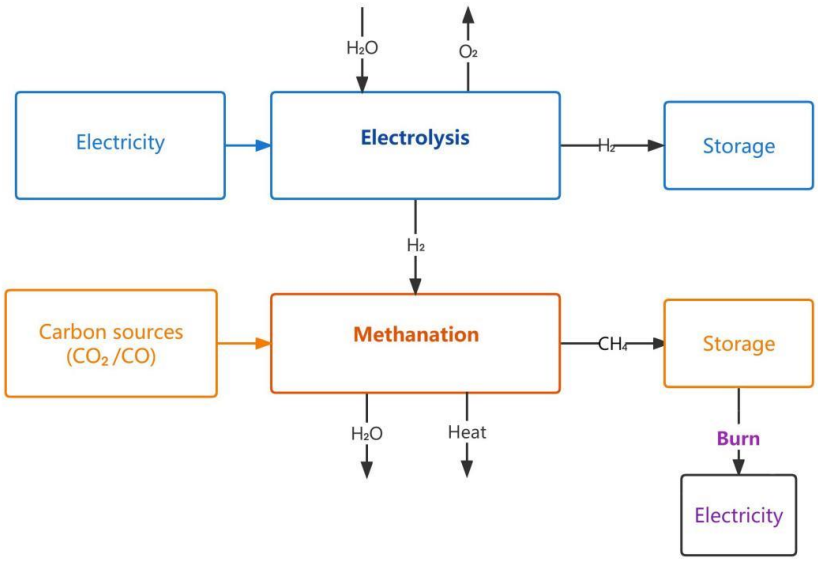


Figure 1. Power to methane technology diagram.

In the past five years, a lot of literature has accumulated a wealth of experience by modeling and making economic or technical studies on the coupled P2G technology for electric-gas systems [7-12]. Some literature proposes technical optimization solutions for different scenarios based on models, some of the literature makes an economic analysis of the technology and draw a conclusion that the technology is costly but has a good economic performance and low carbon profile. The electricity-gas coupled P2G technology can improve the wind power consumption capacity and reduce the operation cost, so it is necessary to make an operational analysis of the electricity-gas coupled P2G system. This paper analyzes the advantages and disadvantages of the technology in the context of the P2G technology process and analyzes the optimal scheduling and operation of the participating P2G systems, and finally makes an outlook on the future application of the technology in the context of practical applications.

The main objective of this paper is to analyze the electricity-gas interconnection energy system and the electricity-gas-thermal multi-energy system based on the existing P2G system to get a better energy dispatch and operation scheme. First, this paper analyzes the advantages and disadvantages of the technology in the context of the P2G technology process and presents the problems to be solved. Then, with the dispatching objective of reducing operating costs, the participating power-gas system model and the power-gas-heat multi-energy system model are analyzed to obtain the optimization scheme. Finally, the technology is combined with practical applications to provide an outlook on future applications.

2. Technology of Power to Gas

2.1. Advantages

P2G converts the energy to substance instead of just change the type of the energy. This means that it turns the question of how to store energy into how to store material such as methane. Converting of methane into electricity can fall back on established power plant technology. The technology can operate on the basis of existing equipment. This is very important for a technology that has not been widely used. Because that means that there is no need to build too many special equipment when applying this technology. When the factory wants to replace the original technology with P2G, there won't be too much time and money wasted on it. Ease of installation of this technology puts it in a favorable position in the wave of technology upgrading in the future. P2G can achieve the storage capacity that traditional energy storage technology cannot achieve. The rated power of large-scale P2G equipment can reach gigawatt level, and the discharge time is several days or even months [13].

In contrast, the superconducting energy storage and flywheel energy storage capacity are small, the rated power is between kW and MW, and the discharge time is short. The huge reserves make the P2G technology can be used to regulate all kinds of fluctuating energy supply. That is, store part of the energy when the energy supply is too much, and appropriately supplement the energy to the system when the energy supply is insufficient [14]. Due to the characteristics of P2G technology that converts energy storage into material storage, P2G can realize energy storage for a long time. Most electric gas conversion equipment can be stored for 50 years. In contrast, energy storage technologies such as batteries are difficult to store such long-term energy in advance.

As mentioned before, the technology can convert energy into methane. Methane is a widely used material, whether as energy supply or industrial raw material. When energy is needed, methane can be used as fuel or converted into electricity through technology to meet the energy supply. If there is a lack of industrial raw materials, the stored methane can also be directly used for industrial production. The application of this technology is very flexible. Although it aims to solve the problem of energy storage, the stored methane can also be used in different aspects such as industrial production. Compared with similar electric conversion of hydrogen, the product obtained by electric conversion of methane become more stable and safer, and the energy efficiency is also higher. Hydrogen is prone to danger during transportation and is difficult to store. At the same time, the energy density of hydrogen is only a quarter of that of methane. Whether from the perspective of safety or energy density, electric conversion of methane is a better choice. Electricity to gas technology is a process from energy to gas and then to energy. CO2 needs to be consumed in the process of converting energy into gas, and CO2 will be released in the process of gas to energy. According to this feature, using CCS and other technologies, CO2 can be used in the system in the P2G process, so that CO2 will not be directly discharged into the atmosphere. It prevents CO2 from entering the atmosphere and intensifies the greenhouse effect.

2.2. Disadvantages

However, there are still some areas for improvement in this technology. Methane will leak during storage, which is almost inevitable. If methane leaks into the atmosphere, it will have about 20 times the impact of CO2 on the greenhouse effect. Methane might leak during transportation and storage, which is almost inevitable. If methane leaks into the atmosphere, it will have more than 20 times the impact of CO2 on the greenhouse effect. Unlike the CO2 mentioned above, methane leakage is not concentrated in one place or at one time, so it is difficult to collect the leaked methane. The only possible way to improve this defect is to select more sophisticated equipment to reduce the possibility of methane leakage in all links.

The electrical conversion efficiency of P2G technology is not satisfactory. Compared with other energy storage technologies, the energy conversion efficiency of P2G is low. When energy is converted into methane, the efficiency is about 60%, while when energy is converted into methane for storage and methane is converted into energy, the efficiency is only about 33%. Energy is lost in the form of heat in the process of combustion, synthesis, etc. At the same time, methane leakage also caused some energy loss, but the proportion is small, only about 3%. The energy loss of the whole energy storage process from beginning to end has reached about 76%, which makes the P2G technology have huge reserves, but the efficiency is very low [14]. The high energy loss also greatly reduces the cost performance of the technology. There is also a fatal disadvantage of P2G technology, which is the high operation cost. This is also one of the reasons why the P2G technology has not been officially put into large-scale use. The annual operating cost of an P2G device can reach millions of dollars, compared with an ordinary lithium battery that costs only $50 and can be used thousands of times. This is also related to the late emergence of P2G technology and the imperfect related technology. The high operating cost seriously hinders the actual use of P2G technology. How to reduce the cost of this technology will be a problem of great concern [1].

3. Possible implementation

3.1 The operation and optimal scheduling of the energy and electricity system

With the increasing environmental pressure and growing demand for energy, the third industrial revolution with the energy Internet as the core came into being, in order to solve the major issue of energy dispatch and utilization [15]. In the framework of the Energy Internet, P2G can participate in the dispatching and operation of electricity and natural gas systems, offering a new approach of thinking to solve the storage and utilization of energy: through P2G technology, surplus electricity is converted into methane and injected into the natural gas pipeline network transportation and storage, and on this basis, by scheduling the electricity system with the natural gas network, the capacity of the energy system to take in electricity could be observably improved [16].

As a crucial primary energy source, methane is more closely linked to the electricity system, making the application of an interconnected electricity-gas-thermal energy system possible. P2G technology can reuse energy by converting surplus thermal power in low hours or into natural gas that can be conveniently stored on a large scale and generating electricity via gas turbines in peak period. Compared to conventional energy storage equipment, the large storage capacity and long discharge time of P2G can effectively improve the flexibility of large-scale thermal power unit operation [17].

CO2 capture from the exhaust gases of thermal power plants is used as the main source of CO2 needed for electricity to gas conversion. The technology of CO2 capture for coal-fired power plants is a crucial means of reducing greenhouse gas emissions and combating climate change [18]. Furthermore, the thermal energy generated during the P2G conversion process can be used by thermal power plants. The structure of an interconnected P2G energy system is shown in Fig. 2.

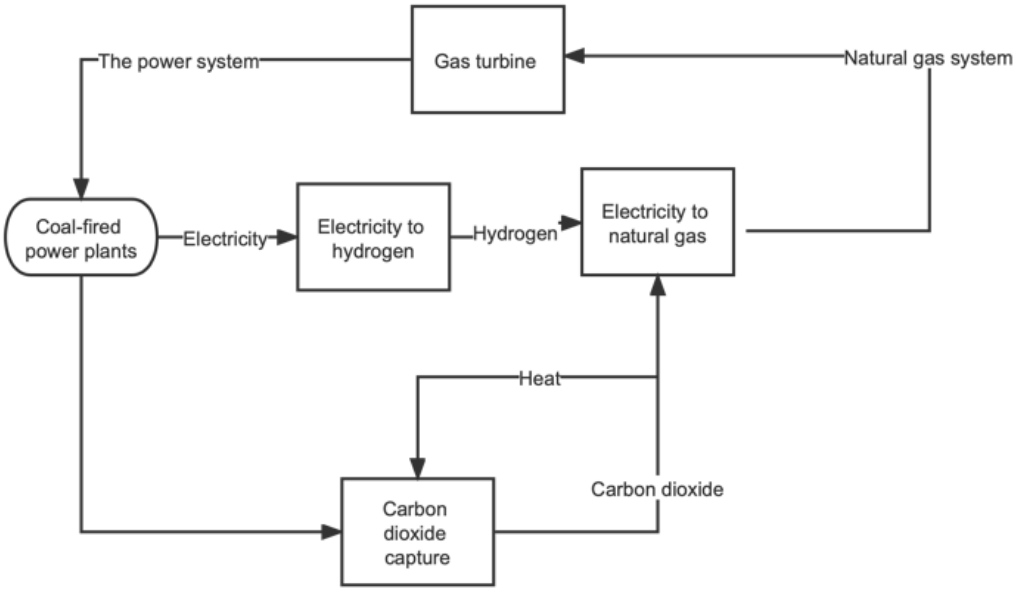


Figure 2. Structure of an interconnected electric-gas energy system [18].

The electricity-gas-heat multi-energy system consists of an energy center and a transmission network, with the P2G technology included in the energy center module. During normal operation, the electricity-gas-heat multi-energy system can be either a power source or a load, depending on the current operating conditions, and the system is dispatched by the dispatch center. The dispatching steps are as follows: Firstly, each energy center forecasts the load of different energy sources such as electricity load, natural gas load and heat load for the following day and submits it to the system dispatching agency. Secondly, the system scheduling agency draws up a scheduling plan for each energy center according to certain scheduling objectives (e.g., minimum system operating costs) and considering system operating constraints. Thirdly, the energy converters and gas storage equipment

within each energy center operate in accordance with the dispatching plan drawn up by the system dispatching agency.

The various energy sources (e.g., electrical energy, natural gas) acquired by the energy centers from various networks are transformed and transmitted within them to meet their internal demand for various energy sources. The operation of the energy centers can be improved by optimizing the amount of energy input to the energy centers and the dispatch coefficients of the converters in this way, enabling the interconversion of electricity-gas-heat loads and saving system operating costs.

3.2 PTG and renewable energy generation

Renewable energy will gradually substituting traditional fossil fuels such as coal as the main primary energy source under the framework of the new-type energy internet. However, the fluctuating and intermittent nature of renewable energy generation output, represented by wind power, has restricted its application, leading to wind farm abandonment, among other things. The P2G technology that has been maturing in recent years offers a new way of thinking about the storage and utilization of large amounts of renewable energy: through P2G equipment, surplus electricity is converted into man-made methane and transmitted into the natural gas network for transmission and storage, on the basis of which the system's ability to accept renewable energy generation can be significantly increased by scheduling the operation between and natural gas network and the energy system. For example, wind power is generally higher around midnight and the system load is at a low level. For power systems with wind power penetration, the pressure to consume wind power around midnight is high, and if the regulation capacity of the system is insufficient, the wind must be abandoned, thus wasting green resources. At this time, the P2G equipment in the energy center is used to store the excess wind power in storage tanks or natural gas pipelines, which is equivalent to increasing the electrical load and improving the system's ability to accept wind power [19]. Local combined heat and power unit (CHP) supply from the energy center can be activated during the day when the electrical load is high [16].

3.3 Application

Germany is committed to its CO2 reduction targets and has introduced a large amount of renewable energy but is constrained by the availability of stable renewable energy such as bioenergy and must rely on variable renewable energy sources such as wind and photovoltaics. Given the variable nature of the output of photovoltaic and wind power generation, it is necessary to control and stabilize the output to reduce the portion of power generation that exceeds demand.

With the spread and expansion of renewable energy sources, the excess of renewable energy electricity has increased dramatically and has become a social problem in Germany. Thanks to its extensive and well-developed infrastructure of underground storage and natural gas pipelines, Germany has successfully adopted the renewable energy P2G strategy and is the most successful country in the world in terms of CO2 emissions reduction and renewable energy use.

Currently, there are more than 20 P2G projects in Germany, including planned and ongoing projects. The total number of P2G projects in Europe amounts to more than 30, with a breakdown of projects. Of the products produced by P2G, significantly more are injected into the natural gas pipeline network than are used for transport, hydrogen and methane are used in roughly equal quantities, and most of the renewable electricity utilized is variable load. It has also been reported that as of January 2016, 50 P2G demonstration projects have been completed in Europe. For example, the Audi validation project in Germany uses hydrogen and CO2 from renewable electricity to produce methane, with the CO2 supplied by an adjacent bioenergy plant. The resulting synthetic methane is delivered to compressed natural gas (CNG) stations through existing natural gas pipelines. Germany already has more than 1,000 CNG stations and the cost of transporting the hydrogen to CNG stations is reduced compared with supplying hydrogen directly to a fuel cell cars, which requires new infrastructure [20].

4. Conclusion

With increasing concerns about resources and the environment, there is a trend to develop efficient and clean energy technologies. P2G technology can rely on existing power plant technology as well as the natural gas pipeline network. In addition, this technology has the advantages of large capacity, long-term seasonal energy storage and stable products. However, at this stage, the conversion efficiency is low compared to other technologies, and there is a risk of leakage of the product methane during transportation and storage. Methane causes more than 20 times the greenhouse effect than CO2, so methane leakage is a problem that must have a solution in the application of P2G technology. In the future, researchers should work on solving the problems of low efficiency as well as methane leakage for larger-scale industrial applications. The widespread application of P2G technology to integrated electricity-gas-heat systems can make the system more flexible. P2G technology enables the storage of electricity generated from various renewable energy sources, and indirectly reduces the electricity consumption of fossil fuels and other fossil fuels and promotes a win-win situation for all parties in the energy grid, which has a good development trend and application prospect.

References

[1] Ma Jianli, Li Qi, Chen Xiangrong, Li Xiaochun, Tan Yongsheng, economic analysis of geological energy storage technology from electricity to gas%j Engineering Science and technology, 54 (01) (2022) 117-127.

[2] D. Hidalgo, J.M. Martín-Marroquín, Power-to-methane, coupling CO2 capture with fuel production: An overview, Renewable and Sustainable Energy Reviews 132 (2020) 110057.

[3] H. Blanco, W. Nijs, J. Ruf, A. Faaij, Potential of Power-to-Methane in the EU energy transition to a low carbon system using cost optimization, Applied Energy 232 (2018) 323-340.

[4] P. Li, Techno-environmental assessment of gas-based power plant and renewable unit in the presence of power to gas system and gas storages for emission reduction using information gap decision theory, Journal of Energy Storage 51 (2022) 104382.

[5] M. Qi, J. Park, R.S. Landon, J. Kim, Y. Liu, I. Moon, Continuous and flexible Renewable-Power-to-Methane via liquid CO2 energy storage: Revisiting the techno-economic potential, Renewable and Sustainable Energy Reviews 153 (2022) 111732.

[6] X. Zhang, Y. Bai, Y. Zhang, Collaborative optimization for a multi-energy system considering carbon capture system and power to gas technology, Sustainable Energy Technologies and Assessments 49 (2022) 101765.

[7] S. Yamamoto, S. Sayama, S. Kunitomi, K. Ogasawara, N. Baba, Demonstration of a high-efficiency carbon dioxide capture and methanation system with heat/material integration for power-to-gas and zero carbon dioxide emissions in flue gasses, International Journal of Greenhouse Gas Control 114 (2022) 103584.

[8] J. Ikäheimo, R. Weiss, J. Kiviluoma, E. Pursiheimo, T.J. Lindroos, Impact of power-to-gas on the cost and design of the future low-carbon urban energy system, Applied Energy 305 (2022) 117713.

[9] D. He, Y. Yu, C. Wang, B. He, Maximum specific cycle net-work based performance analyses and optimizations of thermodynamic gas power cycles, Case Studies in Thermal Engineering 32 (2022) 101865.

[10] S. Morgenthaler, C. Ball, J.C. Koj, W. Kuckshinrichs, D. Witthaut, Site-dependent levelized cost assessment for fully renewable Power-to-Methane systems, Energy Conversion and Management 223 (2020) 113150.

[11] M.P. Novoa, C. Rengifo, M. Figueredo, Steady and Dynamic State Simulation-based Study of the Coupling of Electrolysis and Methanation Processes within Power to Methane (PtM) Context, in: M. Türkay, R. Gani (Eds.), Computer Aided Chemical Engineering, Elsevier2021, pp. 1093-1098.

[12] P. Straka, A comprehensive study of Power-to-Gas technology: Technical implementations overview, economic assessments, methanation plant as auxiliary operation of lignite-fired power station, Journal of Cleaner Production 311 (2021) 127642.

[13] A. Maroufmashat, M. Fowler, Transition of Future Energy System Infrastructure; through Power-to-Gas Pathways, 10(8) (2017) 1089.

[14] V. Eveloy, T. Gebreegziabher, A Review of Projected Power-to-Gas Deployment Scenarios, 11(7) (2018) 1824.

[15] Dong Chaoyang, Zhao Junhua, Wen Fushuan, Xue Yusheng, from smart grid to energy Internet: basic concepts and research framework%j power system automation, 38 (15) (2014) 1-11.

[16] Li Yang, Liu Weijia, Zhao Junhua, Wen Fushuan, Dong Chaoyang, Zheng Yu, Zhang Rui, cooperative dispatching and wind power consumption benefit analysis of electricity gas heat system including electricity to gas%j power grid technology, 40 (12) (2016) 3680-3689.

[17] T. Brown, D. Schlachtberger, A. Kies, S. Schramm, M. Greiner, Synergies of sector coupling and transmission reinforcement in a cost-optimised, highly renewable European energy system, Energy 160 (2018) 720-739.

[18] Wang Xinming, Xun Zhiwei, Yang peihao, application of electricity to gas technology and comparison with other energy storage methods% J Shanghai electric technology, 12 (01) (2019) 18-22.

[19] R. Zhang, T. Jiang, F. Li, G. Li, H. Chen, X. Li, Coordinated Bidding Strategy of Wind Farms and Power-to-Gas Facilities Using a Cooperative Game Approach, IEEE Transactions on Sustainable Energy 11(4) (2020) 2545-2555.

[20] Luo Chengxian, Germany adopts electricity to gas technology to realize low-carbon%j domestic and foreign energy, 22 (04) (2017) 20-26