Theory and Practice of Science and Technology
2025, VOL. 6, NO. 3, 124-129
DOI: 10.47297/taposatWSP2633-456924.20250603

Summary of fuel cell cogeneration technology

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ABSTRACT

This paper introduces the research progress of fuel cell cogeneration technology. As a distributed energy conversion device, fuel cell has the advantages of high energy conversion efficiency, low environmental pollution, low noise and so on. Cogeneration technology can realize the efficient output of electricity and heat at the same time, further improving the efficiency of energy utilization. Faced with severe problems such as the traditional energy crisis and the intensification of greenhouse effect, fuel cell cogeneration technology has become one of the most promising technologies in the future. This paper introduces the principle, technology status, system integration and optimization of the fuel cell cogeneration system, and discusses its application prospect and challenges in the field of distributed energy, providing a reference for the future development of the technology.

KEYWORDS

fuel cell; cogeneration system; hydrogen energy; development status

1 Background significance

In the past 50 years, with the rapid growth of the world population and the rapid development of economy, the consumption of traditional fossil energy has increased sharply, and the problems of energy depletion and environmental damage brought by it have become increasingly acute. Faced with the grim situation, all countries in the world attach great importance to the issue of energy transformation, and increase the investment in efficient power equipment and renewable energy. China's fossil energy consumption accounts for about 83.4% of the total energy consumption in 2021, and energy transformation is urgent [1]. Therefore, in September 2020, China put forward the energy social development goal of "carbon peak before 2030 and carbon neutrality before 2060", also known as the "double carbon" goal, and vigorously develop renewable energy technologies [2]. Among them, fuel cell (FC) technology has attracted much attention. Fuel cell is a distributed energy supply [3], the reaction products are only water and CO2, almost pollution-free, and due to high power generation efficiency, less fuel is required for a given power generation, and less emissions. CO_2At the same time, fuel cell has the advantages of low noise, safety and reliability, so as a new type of environmental protection energy, it has become one of the most promising technologies in the future, and it is increasingly widely used in all walks of life in society.

2 Introduction of fuel cell cogeneration technology

2.1 Fuel Cell (FC)

The core components of a fuel cell are electrode stacks, electrolytes and external circuits. Unlike normal batteries, the reactant, or fuel, is placed outside the electrodes when not working. When the fuel passes through the cell, it converts chemical energy into electricity through a REDOX reaction. There are many types of fuel cells [4], and depending on the fuel, electrolyte, and catalyst they use, They can be divided into proton exchange membrane fuel cells (PEMFC) [5], solid oxide fuel cells (SOFC) [6], alkaline fuel cells (AFC) [7], molten carbonate fuel cells (MCFC) [8], phosphoric acid fuel cells (PAFC) [9] and direct methanol fuel cells (DMFC) [10]. Their operating conditions and characteristics are shown in the following table.

Among them, PEMFC and SOFC are the most widely used. PEMFC takes polymeric film as electrolyte, relies on precious metal catalyst, is generally only used as fuel, and is sensitive to CO and other gases. H_2Pemfc has low operating temperature, low noise and high heat output, and is widely used in small cogeneration facilities, such as electric vehicles and residential buildings. SOFC uses solid oxides as electrolytes, and the fuel gas first H_2CO_2undergoesH_2 methane reforming reaction and water vapor conversion reaction to convert it into a gas mainly composed of and, which is then discharged by medium temperature pressure swing adsorptionCO_2/separation technology [11] for REDOX reaction. CO_2H_2The temperature of SOFC reaction is very high, 600~1000℃, and the activity of the reaction gas is high, so there is no need for precious metal catalyst and the cost is low. At the same time, due to the high quality of waste heat, it is suitable for supporting the use of CHP facilities.

It can comprehensively utilize a variety of hydrocarbon gases such as natural gas, biogas, and gas, and has wide fuel adaptability. For the above reasons, it is generally used in large-scale power generation facilities, such as distributed power stations.

Table 1 Types and characteristics of fuel cells

Battery	Fuel	Electrolytes	Catalyst	Operating temperature	Power generation efficiency	Applications
PEMFC	H_2	Polymeric membrane	platinum-based	<120℃	60%	Portable, distributed power generation
SOFC	H_2, natural gas, biomass gas, etc	Solid oxides	Nickel base	500℃-1000℃	60%	Distributed power generation
AFC	H_2	KOH solution	Platinum base	<100℃	60%	Submarines, aerospace, etc
MCFC	H_2, natural gas, biomass gas, etc	Molten carbonate	Nickel base	600℃-700℃	50%	Industrial power, large public power
PAFC	H_2	H_3PO_4Solution	platinum-based	150℃-200℃	40%	Distributed power generation
DMFC	H_2	Polymeric membrane	platinum-based	<120℃	40%	Portable power generation

2.2 Combined Heat and Power System (CHP)

Combined heat and power system (CHP) generally refers to the reuse of waste heat generated during the operation of power generation equipment or heat engine, so that it is re-converted into electrical energy or direct heating equipment. For fuel cells, the CHP system not only has the function of ensuring the temperature of the battery and the stable operation of the equipment, but also can effectively use the waste heat that can not be used in power generation, and play the role of heating while supplying power. When the quality of waste heat is low, the water cooling method can be used to heat the water in the system and heat the required parts. When the waste heat quality is high, power generation can also be re-generated by steam power cycle, organic Rankine cycle (ORC), supercriticalCO_2 cycle and other power cycle methods, again improving energy quality and utilization, and reducing carbon emissions. Fuel cell combined heat and power system (FC-CHP) can use the waste heat generated during the work to heat, to achieve comprehensive cascade utilization of energy, greatly improve the efficiency of fuel utilization, and is very important for the construction of energy-saving society.

At present, the research of CHP system mainly focuses on thermal management, system integration and durability optimization.

The main purpose of thermal management is to remove excess heat and ensure a constant operating temperature of the fuel cell. Effective thermal management can improve the performance and life of the fuel cell and ensure the stable operation of the system. For PEMFC-CHP, literature [12] developed a temperature control method for reactor and storage tank based on MPC control, and compared it with PID controller under the same situation. The results show that it can effectively control the temperature of the reactor and the water storage tank, and has better tracking and anti-jamming ability than PID. MPC can control the temperature of PEMFC reactor at 60±0.0077℃, which is obviously lower than the temperature error of PID control at 0.33℃.

Multi-module coordination is the key of system integration to realize multi-module cooperative work. The system performance and economy can be improved by optimizing the system capacity configuration and changing the control strategy. Based on the photohydrogen FC-CHP system, literature [13] formulated control strategies to comprehensively coordinate the start-stop sequence and output size of each module, so as to solve the problem of low efficiency in the low power operation interval of the electrolyzer. And the improved particle swarm optimization algorithm was used to calculate the optimal allocation scheme of the comprehensive cost capacity of the system. The proposed scheme can reduce the comprehensive cost by 2.2% compared with the traditional scheme.

Durability optimization involves material selection, manufacturing process improvement, etc., to extend the service life of the fuel cell. Improving durability can reduce system maintenance costs and improve economy and market competitiveness. In literature [14], the in-situ durability of Au coated metal bipolar plate was verified at the stack level for 5000h under on-board working conditions, and it was pointed out that improving liquid water management during low-temperature operation and avoiding the phenomenon of high temperature (> 85℃) in the stack was an important way to effectively mitigate the durability attenuation.

3 Application prospect

3.1 Combine with other energy sources

Fuel cells can be coupled to a variety of other novel hydrogen production technologies depending on the source of hydrogen energy. In areas rich in certain energy sources, it is possible to achieve self-sufficiency in the production and utilization of electric heating, and even generate surplus electricity to feed into the grid for other areas. Therefore, fuel cell technology can be adapted to the energy needs of various regions.

When the source of hydrogen energy is traditional fossil fuel, fuel cell power generation is cleaner and more efficient than the traditional way, and gradually expanding the application can realize the smooth transition of energy social transformation. At present, coal gas and hydrogen-doped natural gas are available for application. The simulation model of coal gasification fuel cell cogeneration system (IGFC-CHP) based on SOFC is proposed in literature [15], which can effectively realize in-situ capture and storage (CCS). CO_2Aiming at the disadvantages of high ash and sulfur content of traditional gas, the coal gasification module is redesigned and the feasibility of the system is verified. The analysis of literature [16] shows that it is feasible to apply hydrogen-doped natural gas directly to SOFC and after separation to PEMFC. H_2Literature [17] analyzed the possibility of using the existing natural gas pipeline to transport, and designed the domestic PEMFC-CHP system of hydrogen-doped natural gas. The simulation results showed that the fuzzy PID control could achieve stability faster and save energy.H_2

When the hydrogen energy source is renewable, the fuel cell is almost pollution-free and emits only a small amount, which makes it possible to achieve the goal of carbon neutrality. CO_2For example, the surplus electricity generated by wind and light can be used to produce hydrogen. It is usually stored in the hydrogen storage tank, and then transported by it to drive the fuel cell when electricity is needed. H_2H_2This method can effectively solve the contradiction between the instability of renewable energy and the fluctuation of electric heating load. On this basis, flexible heat load can also be considered to save costs and reduce the rate of power abandonment [18]. Wind energy can be used on islands. Zhejiang State Grid Taizhou Dachendao Hydrogen Energy Comprehensive Utilization Demonstration Project, relying on the rich wind resources of Dachendao Xingxing Wind Farm, built a 100kW electrolytic water hydrogen production system, using PEM electrolytic hydrogen production and CHP technology, the comprehensive efficiency is as high as 96.1%[19]. For the vast rural areas, biomass resources can be utilized, and the combined SOFC-ORC-CHP system can greatly improve the power generation efficiency to about 56% compared with the traditional method [20]. For example, modern facility agriculture has a wide range of greenhouses and seedling factories, and the application of SOFC-CHP system can effectively solve the problems of thermal insulation and electricity consumption, and is cleaner, more efficient and pollution-free than the traditional way [21].

3.2 Diversified application scenarios

Fuel cells can be used in residential buildings such as single family, residential area and industrial park, and different types of fuel cells can be selected according to local conditions according to the characteristics of the application area. For example, the southern region of China uses SOFC-CHP with high power output, and the northern region uses PEMFC-CHP with high heat output. Literature [22] takes a villa area in Shenyang as the research object, evaluates the sunshine conditions throughout the year in typical northern areas of China, and proposes a new system combining PEMFC-CHP with PV/T integrated components. It is analyzed that the system can achieve stable operation throughout the year and self-sufficiency in energy utilization. Based on the energy consumption analysis of a residential building in Beijing, literature [23] also verified the feasibility of the construction of PEMFC-CHP. According to the photovoltaic FC-CHP used in industrial parks, literature [24] considers the uncertainty of hydrogen conversion technology (SOFC, PEMFC, PEM electrolysis cell, lithium battery) and the cost uncertainty of the key components of corresponding technology, constructs a virtual application scenario, and sets a mixed integer linear programming model to solve the problem with the goal of cost optimization. And a solution with reference value was obtained. The completed construction project of Youkede Data center in Ulanqab City, Inner Mongolia, mainly has electric heating load from office and living areas, and the use of fuel cell cogeneration can reduce carbon emissions by 469.5 tonsCO_2/year [25].

FIG. 1 Yucode Data Center in Ulanqab City, Inner Mongolia

The fuel cell generates electricity and drives the motor, which can replace the traditional internal combustion engine as a power application in transportation vehicles. Literature [26] proposes an improved tree optimization algorithm for cogeneration microgrid considering EVs participation in scheduling. The new algorithm reduces the total cost by 19.15%, and the convergence time is shortened by 6.4% under the same iteration. Literature [27] proposes a scheme to apply SOFC-CHP to ships, using the organic Rankine cycle (ORC) of exhaust gas turbine (ET) to recover waste heat and drive the ship, forming an ET/SOFC hybrid power model. The research results show that R245fa is the best organic working medium, and the net output power can reach 55.68kW.

4 Development status and application examples at home and abroad

From the policy point of view, the world's major developed economies, such as the United States, Japan, Europe, South Korea, all attach great importance to fuel cells and their cogeneration technology, in recent years through the release of a series of industrial subsidy policies to encourage the research and development and promotion of fuel cells and hydrogen energy industry.

4.1 United States

The United States was the first country to conduct research on SOFC technology. [28] Since 1995, the United States Department of Energy (DOE) has funded $750 million in SOFC research and development to improve system power generation efficiency, extend service life and reduce costs. Bloom Energy has developed a SOFC power generation system called Bloom box, which has been used on the campuses of large companies with high power costs, such as Google, Walmart, Coca-Cola and eBay [29]. FuelCell Energy has installed more than 300MW of distributed cogeneration systems using natural gas and biogas as fuel MCFC around the world. The generation efficiency is 47%~60%, and the combined efficiency of cogeneration can reach 90%.

4.2 Japan

Japan attaches great importance to fuel cell technology, and even lists it as the first of the seven emerging strategic industries that the country will focus on promoting [30]. Japan also launched the ENE-FARM program in 2005 to vigorously promote the commercialization of household FC-CHP systems, attracting many technology companies such as Aishin Precision, Panasonic, Toshiba and Tokyo Gas Company to compete. The combined efficiency of the combined heat and power generation system using PEMFC and SOFC can reach more than 90%, and the rated power is 700W, which can basically meet the energy demand of the average household. With the continuous improvement of technology, the production cost of each system has dropped significantly, and the selling price of a single PEMFC unit of Aixin Precision Machinery has dropped to about 54,000 yuan, a drop of more than two-thirds compared with 2009. As of April 2021, 424, 000 units have been sold.

4.3 Europe

In 2008, the European Union organized and established the Joint European Fuel Cell and Hydrogen Energy Organization (FCH-JU) to support and promote the full use of fuel cells [31]. European countries have launched Callux, KFW433, Ene-field, PACE and other demonstration projects. Led by FCH-JU, the Ene-field demonstration project was jointly initiated by 27 fuel cell companies including Solidpower, Ballard Power, Seidra and Viessmann, introducing Japanese technology and installing 1, 046 household FC-CHP systems in 12 countries. And also led by FCH-JU PACE demonstration project, on the basis of the results of Ene-field project, further increase the construction efforts to accelerate the large-scale commercialization of fuel cell cogeneration system in European countries.

4.4 China

China's fuel cell cogeneration technology is still in the layout and initial application stage. In March 2022, the National Energy Administration and the National Development and Reform Commission officially issued the Medium and Long-Term Plan for the Development of Hydrogen Energy Industry (2021-2035) [32], which calls for vigorous research and development of key technologies such as electrolytic hydrogen production, high-efficiency catalytic materials, and proton exchange membranes, so as to expand the scale of renewable energy hydrogen production industry on the existing basis. After the release of the plan, the construction of related demonstration projects surged. In July 2022, China's first MW-level hydrogen energy comprehensive utilization demonstration project was put into operation in Lu 'an, Anhui Province, which is the first domestic verification of hydrogen energy technology with comprehensive independent intellectual property rights [33]. In February 2023, the first SOFC-CHP system designed and produced independently in China was put into use in Xuzhou Huaqing Jingkun Energy Co., LTD., which can use industrial by-product hydrogen to generate electricity and heat for industrial parks [34]. The first ammonia-hydrogen fuel cell powered fishing boat developed by the team of Fuzhou University completed its maiden voyage on the Minjiang River. According to reports, the new powered boat can not only reduce carbon emissions, but also reduce the raw material cost by 30% [35]. These achievements clearly confirm China's technological breakthroughs in the FC-CHP system in recent years and its determination to build an energy-saving society.

5 Summary and outlook

This paper introduces the technology of fuel cell combined heat and power (FC-CHP) and its research status and application in recent years. Under the severe environmental situation of the traditional energy crisis and the intensification of the greenhouse effect, the technology is clean, efficient and almost pollution-free, and has been widely used in the world's major developed economies such as the United States, Japan and Europe. In order to achieve the goal of "double carbon" and the major transformation of the sustainable development of the energy society as soon as possible, and further promote the construction of ecological civilization with the environmental protection concept of "green water and green mountains are gold hills and silver mountains", China urgently needs to increase efforts to invest in the research and practice of relevant technologies. To achieve carbon peaking and carbon neutrality in succession in the next 35 years is a long way to go for an emerging industrial country with a large population and a huge energy market.

China's hydrogen energy and fuel cell industries started late, and there are still many development problems. Researchers can also continue to deepen from many aspects of combined hydrogen production such as wind and water, optimize system structure and operating costs, improve comprehensive efficiency, and expand the application range of fuel cell cogeneration technology. The government needs to give active guidance and introduce appropriate subsidy policies to stimulate production.

References

[1] Peace. 13 kinds of energy minerals have been found in China [N]. China energy news, 2022-09-26 (008). DOI: 10.28693 / n. c. Nki nshca. 2022.002000.

[2] Duan Shuqi, Wang Changjian. Design and Performance of PEMFC Cogeneration System [J]. Journal of Hefei University of Technology (Natural Science Edition),2024,47(12):1693-1697+1703.

[3] Kyle F ,Alexis D ,Kevin A , et al.High performance protonic ceramic fuel cell systems for distributed power generation[J].Energy Conversion and Management, 2021248,

[4] ^ O'HAYRE R,CHA S W,COLELLA W, et al. Fuel cell fundamentals[M].Hoboken:John Wiley & Sons, 2016:1-23

[5] Aziz M ,Trinh H P ,Hudaya C ,et al.Coordinated control strategy for hybrid multi-PEMFC/BESS in a shipboard power [J].Electric Power Systems Research,2025,243111495-111495.

[6] KUTERBEKOV K A, NIKONOV A V, BEKMYRZA K Z, et al. Classification of solid oxide fuel cells[J]. Nanomaterials, 2022,12 (7) : 1059

[7] FERRIDAY T B, MIDDLETON P H.A lkaline fuel cell technology-A review[J].International Journal of Hydrogen Energy, 2021, 46(35) : 18489-18510.

[8] Soujanya L S K ,Sastry K R G ,Ramji K , et al.Energy and exergy analysis of an ideal molten carbonate fuel cell (MCFC) and reheat & regenerative braysson cycle hybrid system[J].Engineering Research Express,2024,6(3):

[9] ITO H. E conomic and environmental assessment of phosphoric acid fuel cell-based combined heat and power system for an apartment complex[J]. International Journal of Hydrogen Energy, 2017,42 (23) : 15449-15463.

[10] Yuan Y C , Li Q , Dong F Y , et al. Synthesis and characterization of a novel graft polymer based hydrophobic polysulfone main chain and hydrophilic sulfonated polyvinyl alcohol side chain as proton exchange membrane for DMFC[J]. Journal of Polymer Research, 2025, 32 (1) : 25-25.

[11] Li S, Zhang J, Wang Dongdong, et al. Research and demonstration of H2/CO2 separation by pressure swing adsorption at medium temperature from coal to syngas [J]. Clean Coal Technology,2023,29(03):92-101.DOI: 10.13226/j.issn.1006-6772.H23010101.

[12] Wang Hui-Min. Thermoelectric management of proton exchange membrane fuel cell system based on model predictive control [D]. Southeast university, 2023. DOI: 10.27014 /, dc nki. Gdnau. 2023.002396.

[13] Shen Hang-Yu, Fan Xiao-Chao, Shi Rui-Jing, et al. Capacity Configuration Optimization of Independent photohydrogen Fuel cell Cogeneration System [J]. Electric Drive,2022,52(22):44-50+65.DOI:10.19457/ J.1001-2095.DQCD23426.

[14] Shu Qing-Zhu. Study on durability attenuation mechanism of Core Materials for proton exchange membrane fuel cells [D]. Dalian jiaotong university, 2024. DOI: 10.26990 /, dc nki. GSLTC. 2024.000013.

[15] Luo Liqi, Xie Guangyuan, Wang Shaorong. Design of cogeneration system for solid oxide fuel cell using gasified gas as fuel [J]. Clean coal technology, 2023, 29 (5) : 68-79. The DOI: 10.13226 / j.i SSN. 1006-6772. H23010102.

[16] Yuan Yijun, Li Jianjun, Pan Weitao. Mixing hydrogen gas application in fuel cells [J]. Journal of gas and heat, 2024, 44 (9) : 12-15. DOI:

10.13608 / j.carol carroll nki. 1000-4416.2024.09.019.

[17] Dai Yong. Design and simulation of domestic PEMFC Cogeneration System based on hydrogen-doped natural gas [D]. Hunan institute of technology, 2023. DOI: 10.27906 /, dc nki. Gnghy. 2023.000208.

[18] Yuan Tie-Jiang, Zeng Jing, Zhang Ming-Yang. Research on Operation Optimization of Household Hydrogen Energy System with Thermal load Flexibility [J]. Acta Solar Energy Sinica,2024,45(07):29-40.DOI:10.19912/ J.0254-0096.tyNXB.2024-0007.

[19] Placed. The domestic first island hydrogen demonstration project - cogeneration system research [J]. Journal of henan electric power, 2022, (S2) : 81-85. The DOI: 10.19755 / j.carol carroll nki hnep. 2022. S2.028.

[20] Cui Zhiheng, Wang Jiangjiang, Huo Shuojie, et al. Performance analysis of biomass gasification coupled solid oxide fuel cell combined cooling and thermal power supply system [J]. Proceedings of the CSEE,2023,43(23):9192-9204.DOI:10.13334/ J.0258-8013.pcSE.222667.

[21] Jiang Sanping, Cheng Yibing, Chen Jinfang, et al. Modern facility agriculture new energy high temperature solid oxide fuel cell development outlook [J]. Journal of agricultural engineering, 2023, 13 (11) : 46-53. DOI: 10.19998 / j.carol carroll nki. 2095-1795.2023.11.008.

[22] Wang Biao, Yu Liang. Simulation of PV/ T-Fuel Cell cogeneration System based on Trnsys [J]. Energy Conservation,2023,42(08):85-87.

[23] Peng Liju, Li Shuang, Shi Yixiang, et al. Modeling and Energy Supply and Demand Analysis of Fuel Cell COgeneration System for Residential Buildings in Beijing [J]. Proceedings of the CSEE,2024,44(10):3905-3916.DOI:10.13334/ J.0258-8013.PCSE.232278.

[24] Zhang Yumeng, Li Xin, Wang Ningling, et al. Optimization of configuration of hydrogen-electric coupled CHP system with multiple uncertainties [J/OL]. Journal of solar energy, 1-8 [2025-02-13]. https://doi.org/10.19912/j.0254-0096.tynxb.2024-0789.

[25] Yang Hai-Liang, Song Ye-Feng, Yang Lian-Rong, et al. Design and installation of Hydrogen Cogeneration system for Engineering: A case study of Youqide Data Center construction project in Ulanqab City, Inner Mongolia [J]. China Building Decoration,2022,(06):139-142.

[26] Li Hongmei, Li Xiangfan, Lin Zhifang, et al. Optimal dispatch of cogeneration microgrid considering vehicle network interaction [J]. Power Grids and Clean Energy, 2019,40(09):63-73.

[27] Chen Huaiqiang, Wang Zhe, Xia Rui, et al. Joint power of ship waste heat recovery system design and effective analysis [J]. Journal of Marine engineering, 2022, 44 (S1) : 330-337 + 351. DOI: 10.13788 / j.carol carroll nki CBGC. 2022. S1.065.

[28] Jin Wenlong, Jiang Xin. Economy of solid oxide fuel cell and domestic cogeneration [J]. The gas and heat, 2021, 9 (08) : 28-31 + 43. DOI: 10.13608 / j.carol carroll nki. 1000-4416.2021.08.008.

[29] Jia Xuping. Bloom energy launches solid oxide fuel cell micro-power station [J]. Journal of Power Supply Technology,2010,34(06):525-528.

[30] Meng Hao, Lv Zewei, Han Minfang. Analysis of commercial application of domestic fuel cell COgeneration system in Japan [J]. China & Foreign Energy,2018,23(10):1-8.

[31] Zhou Dan. Promotion and Application of Micro-fuel cell Cogeneration in Europe [J]. China&foreign Energy, 2019,25(12):77.

[32] Yang Yue, Yang Ming, Lu Hui. Review the hydrogen industry development in our country [J/OL]. Hongshui river, 2025, (01) : 1-8 [2025-02-13]. http://kns.cnki.net/kcms/detail/45.1146.TM.20250120.1853.002.html.

[33] State Grid Anhui Electric Power: The first demonstration station of comprehensive utilization of megawatt-class hydrogen energy in China is put into operation [J]. Electric Power Security Technology,2022,24(07):9.

[34] Wang Bo. China's first solid oxide fuel cell combined heat and power system is launched [J]. Energy Research & Information,2023,39(01):36.

[35] Zhu Rong. Fuzhou Green Ship splitting blue Sea [N]. Fuzhou Daily,2024-12-06(005).