Status of Development and Sales Strategy of Fuel Cell Systems

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ABSTRACT

Fuji Electric has been working to improve the functions of phosphoric acid fuel cells (PAFCs) and expand their applications. For the Japanese market, we are mainly offering models that have grid independent power supply mode for emergency and models that generate electricity from biogas. For the market outside Japan, we are providing the PAFCs for fire-prevention equipment that utilizes low oxygen concentration exhaust emitted from a fuel cell system. We have also been developing solid oxide fuel cells (SOFCs) for next-generation, high-efficiency cogeneration systems. We are designing, manufacturing and evaluating the performance of them to aim for a electric power generation efficiency exceeding 50%.

1. Introduction

In July 2015, the Agency for Natural Resources and Energy announced in its "Long-term Energy Supply and Demand Outlook" that it expects there to be an increase in the adoption of cogeneration systems that include fuel cells. This expectation was caused by a result of the need for comprehensive energy savings from the viewpoint of achieving a safe, stable, economically efficient, and environmentally compatible energy supply. Compared to other cogeneration systems, fuel cells have a number of advantages such as making it possible to use a variety of fuels, providing high power generating efficiency even at small capacities, contributing to reduced running costs and CO_2 emissions, and excelling in environmental friendliness. Among the different kinds of fuel cells, phosphoric acid fuel cells (PAFCs) have a proven track record of long-term commercial usage with a lifetime of 124,000 hours (about 15 years) or longer, making them a practical choice as a small- and medium-scale cogeneration system. In addition, solid oxide fuel cells (SOFCs) provide even greater power generating efficiency than PAFCs, and for this reason, they are expected to become a practical choice for business applications in the near future.

Fuji Electric started selling its 100-kW PAFCs in 1998. We have streamlined the procurement, manufacturing and engineering processes for PAFCs so that they are used especially for the cogeneration system with a power generating capacity of 100 kW of small- and medium-scale facilities bearing high energy costs. From 2010, our endeavors to improve the life expectancy and installability of fuel cell units facilitated the development and sales launch of our cold-climate compatible "FP-100i" PAFC as an all-in-one package that integrates peripheral equipment (see Fig. 1).

Fig.1 Phosphoric acid fuel cell "FP-100i"

In this paper, we will focus on the specifications and application development of the FP-100i, while also describing our SOFC, which is currently under development as a highly-efficient next-generation cogeneration system(1).

2. "FP-100i" Specifications and Optional Functionality

Table 1 shows the main specifications of the FP-100i. Taking advantage of our strength for developing reforming systems, we have developed new models that use such fuels as city gas, for which supply infrastructure has already been built, and biogas (digestion gas), which is regarded as an up-and-coming renewable energy. Furthermore, we have also added a model to our line-up that is capable of generating power with hydrogen as a highly expectant contributor to next-generation infrastructure. The model has achieved a

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Table 1 Main specifications of “FP-100i”

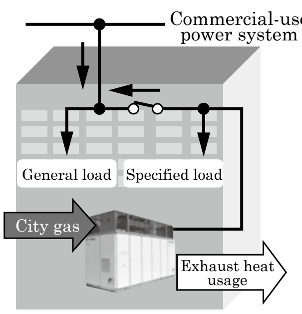
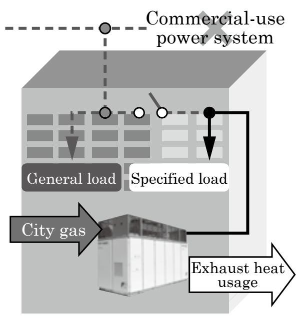
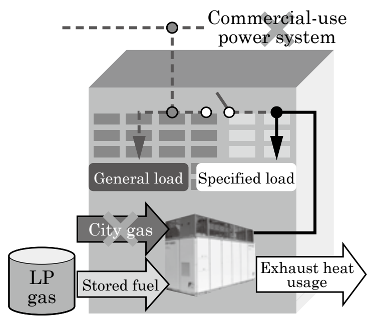
Item	Specifications		
Fuel	City gas	Biogas	Pure hydrogen
Output	105 kW (Power generation end)		
Output voltage/ frequency	210 V/50 Hz or 60 Hz		
Power generation efficiency (LHV)*	42%	40%	48%
Heat output	123 kW	116 kW	99 kW
Total efficiency (LHV)	91%	84%	93%
Exhaust gas	NOx: less than 5 ppm SOx, dust: less than detection limit		NOx, SOx, dust: None
Dimensions	W2.2 × D5.5 × H3.4 (m)		
Weight	14 t		13.5 t

*LHV: When a unit amount of fuel adiabatically and completely combusted under a specific state, and the combusted gas is cooled until it reaches its original temperature, the dissipated heat is called "Heating value." Heating values are classified as either higher heating value (HHV), which contains the latent heat of water vapor, and lower heating value (LHV), which does not contain the latent heat of water vapor.

Table 2 Option line-up for “FP-100i”

Standard compliance	Fuel	Function				Remarks
		Cogeneration	Grid independent power supply	Fuel switching	Low oxygen air supply	
JIS compliance	City gas	○	–	–	–	
		○	○	○	–	Disaster response type
	Digestion gas	○	–	–	–	
	Pure hydrogen	○	–	–	–	
CE compliance	Natural gas	○	–	–	–	
		○	–	–	○	Fire prevention response type
	Pure hydrogen	○	–	–	–	

Table 3 Operation switching during disasters

State	During ordinary use	During power outage	During power outage + city gas stoppage
Switching operation	Grid interconnection operation	Parallels off from the power system and supply power to a specified load	Parallels off from the power system, change fuel, and supply power to a specified load
Output	105 kW	100 kVA	70 kVA
Fuel	City gas	City gas	LP gas (3 hours per 50-kg cylinder)
Operation	Grid interconnection operation	Isolated operation	Isolated operation
Power supply range			

high power generation efficiency of 48%.

In addition to applications as cogeneration systems, we are also offering optional functions, including the disaster response mode, in which the FP-100i can independently supply electricity by using LP gas as backup, and the fire prevention mode, in which it can supply clean low-concentration oxygen air. Table 2 shows the main option line-up for the FP-100i.

3. Examples of Deliveries and Installations in Japan

The adoption of cogeneration systems in Japan saw its peak in 2004 and since then began to decrease due to high fuel prices. However, ever since the Great East Japan Earthquake in March 2011, there has been a growing interest in energy security, resulting in increased adoption. Fuji Electric has developed a model with a grid independent power supply mode for emergencies in order to ensure power supply to critical loads by instantly switching to LP gas when there is a power or city gas outage. This model has been delivered to hospitals and public facilities since these are places of major importance during times of emergency.

Table 3 shows the activation of operation switching during disasters is shown schematically. This model usually operates while connected to a commercial power system. If a power failure occurs, FP-100i can automatically performs parallel off*[1] from the power system, once moves to the standby operation mode, and can start isolated operation approximately 30 seconds after detection of the power failure. Standby operation mode refers to an operation mode in which the fuel cell generates power continuously and solely, and the generated power is consumed inside the power gen-

*1: Parallel off: Disconnection of power generation equipment from power systems

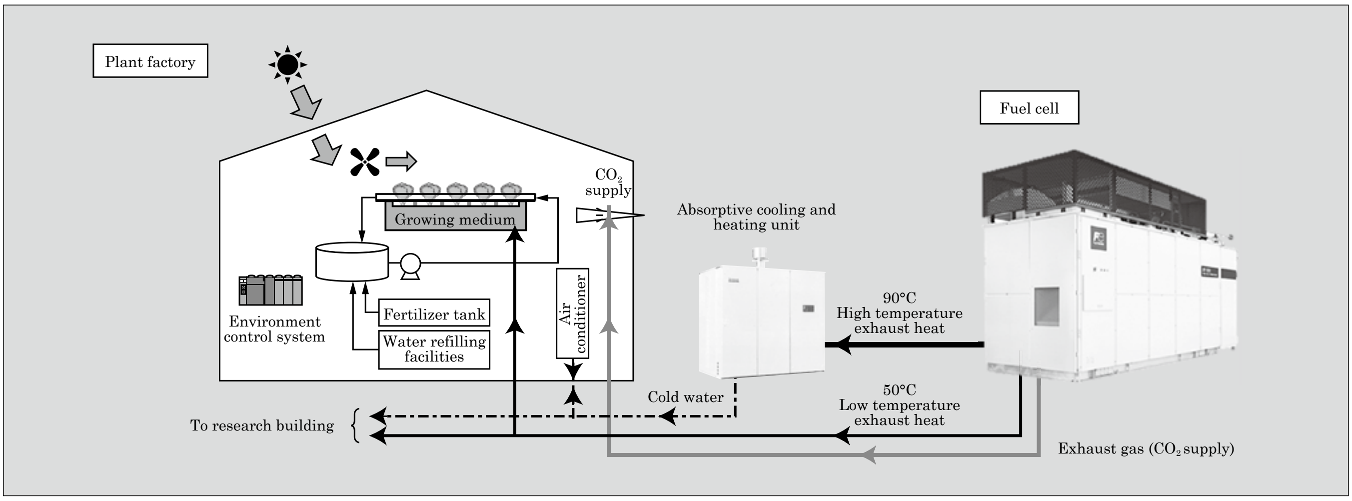


Fig.2 Cogeneration system and supply of CO_2 to plant factory inside Tokyo Factory

Fig.3 Fuel cell facilities installed in Tokyo Factory

erating equipment of the fuel cell. When the fuel cell is connected to a load in a state of isolated operation, sequential turn-on can be made for rotating machines, which may cause in-rush current, by using the overcurrent protection function, load protection function and limiter function. When the city gas supply is stopped, the LP gas operation with 50-kg cylinder can supply electricity for approximately 3 hours, although the output is limited to 70 kVA.

In FY2015, we installed fuel cell facilities in Fuji Electric's Tokyo Factory. The facilities are capable of not only supplying electricity and heat during normal operations, but also independently supply critical loads with power by utilizing photovoltaic cells and storage batteries in case of emergency. Furthermore, we have made use of the clean emissions of the fuel cells in a new application. A portion of the emissions, which have a high CO_2 concentration approximately 150 times the atmosphere, is being supplied it to the annexed plant factory experiment facility to control the plant growing environment (see Fig. 2 and Fig. 3).

In addition, we have been advancing in the use of the fuel cells in a sewage treatment facility following the enactment of the "Feed-in Tariff (FIT) Scheme for renewable energy" in July 2012. When generating power using carbon neutral sewage digestion gas, we can sell the generated power for 20 years at the rate of 39 JPY per 1 kWh. Compared to other types of power generating devices of the same scale, highly efficient power generation fuel cells are capable of generating more power, and thus the installation of the fuel cells have been increasing in number due to the advantages during the life cycle. In FY2014, we delivered a total of 10 units to 4 locations, and in FY2015, we delivered 8 units to one location. We expect the number of inquiries regarding fuel cells to continue to increase in the future.

4. Examples of Deliveries and Installations for Markets Outside Japan

In markets outside Japan, the installation of commercial-use fuel cells has been advancing ahead of household-use fuel cells. Fuji Electric began making shipments to the markets outside Japan in 2010. Up until now, we have delivered a total of 11 units to 4 countries, which include Germany, South Korea, the United States and South Africa.

Germany has decided to stop all of its 17 nuclear power plants by 2022. However, the introduction of renewable energy sources, such as photovoltaic power generation, wind power generation and biogas power generation, has brought about power system instability problems. As a means of mitigating these problems, it is expected that cogeneration systems will play an important role because they can easily adjust the output. Fuji Electric has also devised a new form of added value for cogeneration systems by implementing a method for applying the clean low oxygen air emitted from fuel cells to fire prevention systems that work by reducing the oxygen concentration indoors. These systems have been gaining popularity in Germany, and we have already started delivering them for use in warehouses and data centers. Unlike engine generators that generate power through combustion of fuel and air, fuel cells generate electricity by an electrochemical reaction of fuel and air that are separated by an electrolyte. Fuel cells only selectively consume oxygen in the air during the power generation process and discharge air with a low oxygen concentration that does not contain harmful flue gas. The low oxygen partial pressure located at high altitudes several thousands of meters up not only prevents building materials and paper from igniting, but also has no immediate impact on the human body. As shown in Fig. 4, compared to systems that reduce oxygen concentrations indoors that have conventionally used membrane separation and adsorptive separation to make and supply nitrogen from the air, we have achieved a highly efficient system configuration that suppresses compressor energy consumption (running costs), noise and vibration, while providing a high degree of environmental friendliness. Figure 5 shows the installation state of

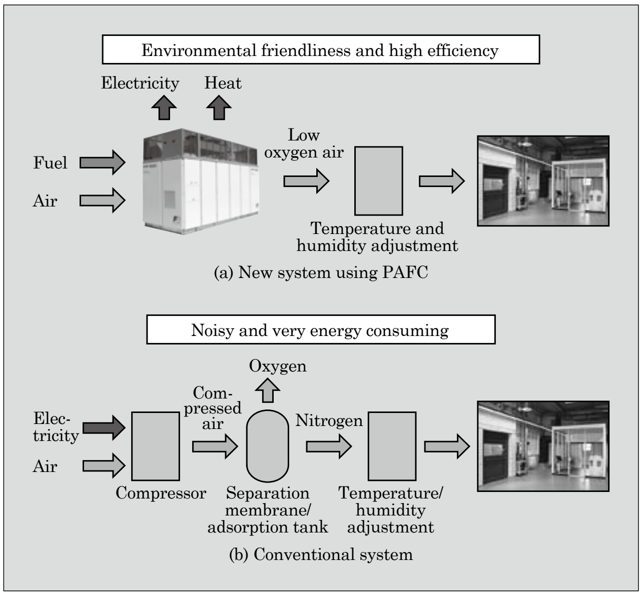


Fig.4 Comparison of systems that reduce oxygen concentration indoors

Fig.5 Fire prevention demonstration system installed in Wismar, Germany

our demonstration system in Germany.

In January 2016, we acquired N_2telligence GmbH, which had expanded our sales of low oxygen fire prevention systems in Germany as our business partner. By taking advantage of its patent and sales network, we will enjoy accelerated sales growth both in Germany and throughout Europe. In order to sell products in the EU, it is necessary to fulfill CE marking obligations. Since Fuel cell facilities are a type of chemical plant that consists of machinery and electrical equipment, they are subject to a wide range of EU directives. Although there was no precedent of Japanese made fuel cells fulfilling CE mark compliance, we took various measures including the modification of devices to acquire compliance certification from a third-party certificate authority. In addition, we also obtained compliance certification via a third-party certificate authority with regard to Germany's VDE 4105 system interconnection standard.

In Germany, a low calorie gas that contains about 10% nitrogen is used in many regions as a city gas. A fuel processing device converts the fuel gas into a gas that contains a large amount of hydrogen inside the fuel cell, and after this it is supplied to the fuel cell unit to enable power generation. Conventionally, whenever the fuel processing device used a fuel gas that contains a large amount of nitrogen, it would generate ammonia as by-product, which is harmful to the fuel cell unit. We have developed a fuel processing device that convert fuel gas including nitrogen into hydrogen-rich fuel gas without producing ammonia by making such improvements as using new catalyst. In the future, we expect that our fuel cells will become more popular in regions that utilize low calorie gas.

In South Korea, a growing demand for commercial-use fuel cells is being facilitated by the government policies, including the "Renewable Portfolio Standard" (RPS) and the obligations of adopting renewable energy for new buildings. Fuji Electric began to ship the fuel cells to South Korea in 2014 and has delivered them to commercial buildings and data centers.

South Africa, which is expected to experience growth as one of the BRICS, has been suffering from severe power shortages due to the deterioration of power generation facilities. Businesses have been actively installing in-house power generation equipment as a means of protecting themselves. In 2014, Fuji Electric delivered a fuel cell to an office building in South Africa. During normal hours, electricity is transmitted to the building via its interconnected system, but during planned power outages, the fuel cell unit makes use of its grid independent power supply mode to provide critical loads with electricity.

Fuji Electric has developed an Internet cloud-based remote monitoring system and maintenance system for fuel cells installed overseas, enabling us to monitor the equipment conditions and update the software from Japan (see Fig. 6). The systems makes

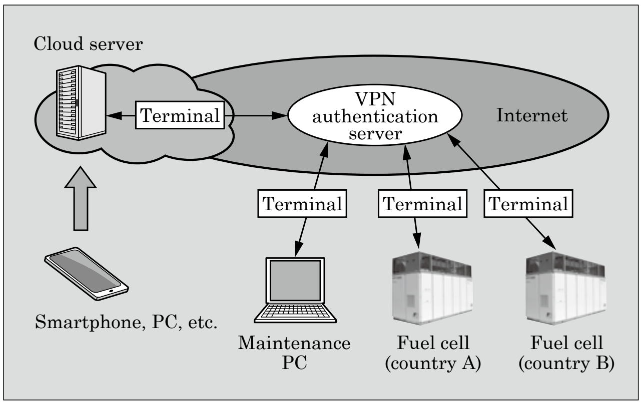


Fig.6 Cloud-based fuel cell remote monitoring system and maintenance system

it possible to simultaneously save operation data to a cloud server while also remotely updating the fuel cell software from a maintenance PC. Therefore, it is possible to view the operation data anywhere anytime by simply logging into the cloud server from a mobile terminal. Using this system is useful to stabilize the operation of the fuel cells.

5. Solid Oxide Fuel Cells (SOFCs)

In addition to PAFCs, we have been advancing the development of SOFCs (see Fig. 7). SOFCs are best characterized for their high power generation efficiency, and we have been aiming for a commercial-use cogeneration system with a capacity of several tens of kW based on the target specifications of the demonstration unit as shown in Table 4. We have been developing this unit under the support of the New Energy and Industrial Technology Development Organization (NEDO) since FY2014. Total efficiency when using all of the recovered heat is close to that of PAFCs, but the electric output ratio is higher than the heat. Therefore, it is capable of economic and efficient operation even when installed at sites where there is not much heat usage.

In FY2014 to FY2015, we worked on the development of elemental technologies such as normal-pressure type fuel cell modules, and during FY2016 to FY2017, we advanced in the design, manufacture and performance evaluation of the demonstration unit for our cogeneration system. Figure 8 shows the equipment configuration of the SOFC that we are currently developing. The system uses an internal reforming cell stack. As a result, it has a simple configuration with only a few main pieces of equipment including a desulfurizer, fuel cell module, exhaust heat recovery unit and anode gas circulation blower. By circulating the exhaust gas (anode gas) on the fuel side of the fuel cell module, the water produced by the fuel cell reaction is circulated, and this, in turn, supplies the steam needed for the reforming reaction of the fuel gas. By doing this, we have aimed to achieve the self-sustained operation of water, thus eliminating the need to replenish the water externally while the unit is operating. In addition, this has made it possible to increase the utilization factor of the fuel for the entire system and also achieve a high power generation efficiency. The self-sustained operation of water is necessary for extending the interval between maintenance work for and suppressing maintenance costs of a water processing device, and as a result, this technology is vital for achieving practicality. Furthermore, we continue to pursue development so as to achieve high power generation efficiency through an optimized design for the fuel cell module, high efficiency via the adoption of a 3-level inverter, and an equipment layout design for the inside of the package that is based on a 3D model thermo-fluid analysis.

Table 4 Target specifications of SOFC demonstration unit

Item	Target specifications
Power generation output	50 kW class
Power generation efficiency (LHV)	50% or more
Exhaust heat recovery efficiency (LHV)	30% or more (hot water output)
Total efficiency	80% or more
Device dimensions	W5.0 × D2.2 × H2.8 (m)

Fig.7 External appearance of SOFC demonstration unit

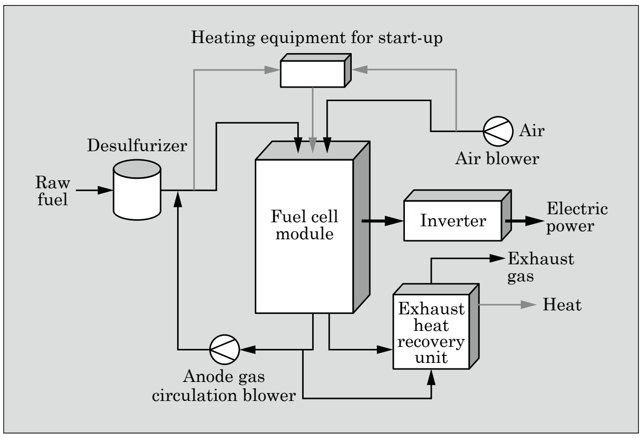


Fig.8 Equipment configuration of SOFC

6. Postscript

We will expand the sales of PAFCs by making the most of their added values, including power supply security functions and fire prevention functions that supply air with a low oxygen concentration, as well as their advantages that they can use a wide range of fuels, such as biogas and hydrogen. In addition to PAFCs, highly efficient power generating SOFCs are also starting to appear on the market for general co-generation systems.

We are making use of our cultivated fuel cell technologies as we aim to take advantage of their features in the development and expanded adoption of various applications not only in Japan, but also throughout the world so that we can contribute to mitigating global warming, protecting the environment and achieving a sustainable society.

References

(1) Koshi, K. et al. Development of Fuel Cells Adapted to Meet New Needs. FUJI ELECTRIC REVIEW. 2013, vol.59, no.2, p.135-139.

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