Development of the FP-100i Phosphoric Acid Fuel Cell

Masakazu Hasegawa † Yoshimi Horiuchi †

ABSTRACT

Since 1998, Fuji Electric has delivered twenty-five 100 kW phosphoric acid fuel cell units. The cumulative operation time of these fuel cells has exceeded the lifespan targeted by the original development (40,000 hours), and their reliability and durability have been proven. In 2009, Fuji Electric began selling the "FP-100i," a newly developed low-cost phosphoric acid fuel cell. Integrated with peripheral devices, the FP-100i features improved ease-of-use and is able to support installation in a wider range of environments. As part of future efforts to popularize and expand usage of the FP-100i, application development will be promoted for fuel cells equipped with disaster response capability, fuel cells that use pure hydrogen or by-product hydrogen, fuel cells equipped with hydrogen supply capability for supplying hydrogen stations for electric vehicles, and so on.

1. Introduction

Fuel cells are power-generating systems that generate electricity directly from a reaction between hydrogen and oxygen, and for which there are great expectations as a next-generation energy source.

Because they are able to extract electricity directly by causing a chemical reaction of their fuel, fuel cells have advantages over conventional internal combustion engines, such as car engines and gas turbines that cause a combustion reaction of the fuel and extract electricity via a generator, of lower loss and higher electrical efficiency. Additionally, in contrast to large-scale centralized power plants, consumers are able to use fuels cells in their vicinity as dispersed local power sources so that the energy loss is low and waste heat can be utilized. Utilizing city gas or the like, a fuel cell internally reforms (converts) that gas into hydrogen, and then uses the hydrogen as fuel to generate electricity. In other words, electricity can be generated as long as hydrogen is present, and since a wide variety of fuels can be reformed into hydrogen, the capability to function as a multi-source energy system is another advantage of fuel cells. For these reasons, fuel cells are attracting heightened interest worldwide for the prevention of global warming and are a promising tool for use in reducing greenhouse gas emissions, and efforts are actively underway to develop and commercialize fuel cell technology.

Fuji Electric has been selling a 100 kW phosphoric acid fuel cell. Aiming to expand sales, Fuji Electric developed a new phosphoric acid fuel cell known as the "FP-100i", and launched this model in 2009. This paper discusses the current status of phosphoric acid fuel cells that have been delivered by Fuji Electric, features of the new FP-100i, and the future outlook for phosphoric acid fuel cells.

† Energy Solution Group, Fuji Electric Systems Co., Ltd.

2. Current Status of Phosphoric Acid Fuel Cells

Fuji Electric began developing phosphoric acid fuel cells in 1973, and has developed 50 kW, 100 kW and 500 kW models for use in onsite applications, and in cooperation with gas companies and electric power companies, has field-tested more than 100 units. This accumulated experience and know-how was incorporated into a 100 kW commercial model that was launched in 1998, and 25 units of this model have been shipped to date.

Table 1 shows the delivery history, the cumulative operating time and the operating status of this 100 kW commercial model. The main operating sites are hospitals, hotels, office buildings, sewage treatment plants and the like. The delivered units are used as co-generation systems that supply electricity and hot water.

This commercial model, when first brought to market, had an overhaul cycle (lifetime of main equipment such as the fuel cell stack and reformer) of 40,000 hours, and has achieved this goal of 40,000 hours at all sites where this model is currently in operation. In particular, a system delivered to a hotel was overhauled after 91,568 hours of cumulative operation, which is longest time record for Fuji Electric.

Since 2006, Fuji Electric has been selling models that support overhaul cycles of 60,000 hours. In addition, with the revision of Japan's "Fire Service Act" in 2006, fuel cells came to be regarded as emergency power sources. In 2008, Fuji Electric's commercial 100 kW model was the first fuel cell to be certified in compliance with the Fire Service Act. During normal operation, this model operates as a co-generation system, but in the event of an emergency, is designed to con-

Table 1 Delivery history and operating status* of Fuji Electric's commercial-model 100 kW phosphoric acid fuel cell

Operating site	Fuel	Overhaul cycle time (h)	Date of delivery	Cumulative operating time (h)	Operating status	Overhaul implementation status
Hospital	City gas (13 A)	40,000	August 1998	44,265	Terminated	
Hotel			March 1999	91,568		Implemented
University			April 2000	41,735		
Office building			March 2001	42,666		
			March 2001	48,734		
			July 2000	64,117	In operation	Implemented
			July 2000	48,269		
Demonstration facility	Biomass gas		July 2001	10,952	Terminated	
Training facility	City gas (13 A)		December 2001	66,442	In operation	Implemented
Sewage treatment plant	Digester gas		March 2002	68,157		
			March 2002	68,391		
Hospital	City gas (13 A)		July 2003	58,160		
University			October 2003	49,731		
Exhibition facility			November 2003	53,199		
Office building			January 2004	51,486		
Hospital			March 2004	48,825		
Exhibition facility		60,000	March 2006	34,646		
Hospital			March 2006	32,155		
Hospital			March 2006	32,377		
Sewage treatment plant	Digester gas		December 2006	29,680		
			December 2006	29,181		
			December 2006	29,068		
			December 2006	29,198		
Government building	City gas (13 A)		September 2007	20,633		
Office building			January 2009	10,700		

* : Operating status as of April 1, 2010

tinuously supply emergency power to a specified load. In the certification examination, this model passed a difficult jet-proof type waterproof test in which water is sprayed from all directions to see whether a failure would occur. In 2009, the FP-100i was awarded a "Nikkei Superior Products and Services Award" that honors outstanding new products and services sold in Japan.

Thus, the reliability and durability of Fuji Electric's phosphoric acid fuel cells have been demonstrated in actual onsite applications.

3. Characteristics of Phosphoric Acid Fuel Cells

Fuel cells are categorized as alkali fuel cells, polymer electrolyte fuel cells, phosphoric acid fuel cells, molten carbonate fuel cells or solid oxide fuel cells, according to the type of electrolyte used, and their operating temperatures, sizes and usages differ. Among these different types, the phosphoric acid fuel cell was the earliest to be commercialized. The main features of Fuji Electric's commercial-model 100 kW phosphoric acid fuel cell are listed below.

(1) High electrical efficiency, from low output to high output

As shown in Fig. 1, high electrical efficiency can be maintained even at partial loads, and load-following operation can be realized. Pattern operation is also possible, whereby the fuel cell runs at its 100 kW rated operation during the day, but at night, runs at partial-loaded operation with a lower output when the usage of electricity is less.

(2) Capable of utilizing multiple sources of fuel

Phosphoric acid fuel cells can accommodate various types of fuel gases with different colorific power, such as LP gas, city gas, digester gas, and hydrogen gas. This capability allows fuel to be switched, and therefore even if a lifeline to city gas or the like is suspended during an emergency, operation can be continued by changing over to a reserve of LP gas or the like.

(3) Excellent environmental characteristics

As can be seen in Fig. 2, the gas emitted from the fuel cell system has extremely low NO_x and SO_x content compared to other types of electric power generators. Moreover, there are no rotating parts since power is generated by a chemical reaction, and the layout inside the fuel cell package and the panel structure are devised such that noise at a distance of 1 m from the fuel cell is less than 65 dB (A). This low noise characteristic facilitates installation at hospitals, hotels or other facilities where quiet operation is required.

Fig.1 Phosphoric acid fuel cell electrical efficiency and image of power load and output power

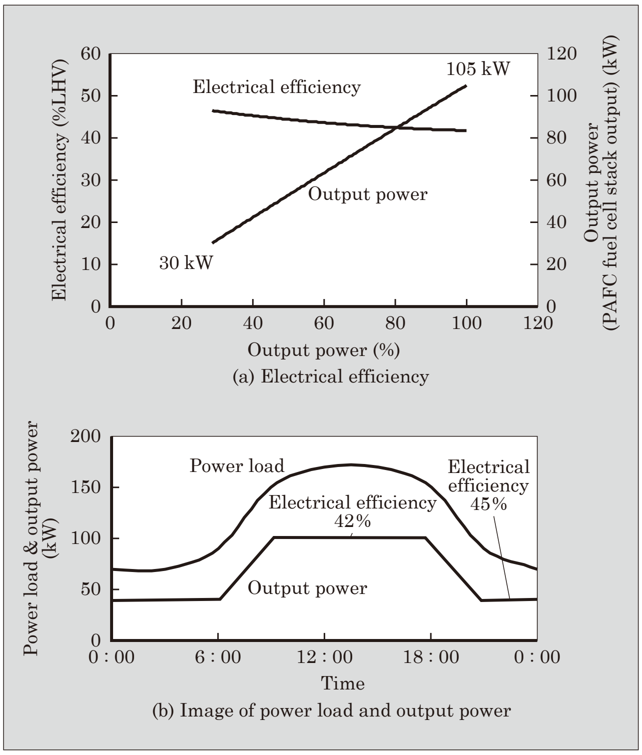
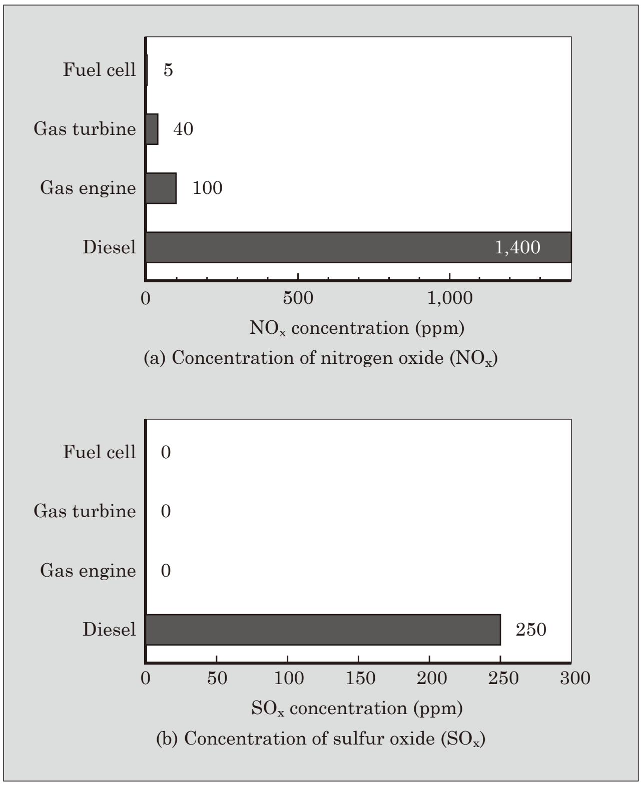


Fig.2 Analysis of exhaust gas from various types of generators



(4) Capable of year-round continuous operation

So that operation can continue stably, the fuel cell operation is halted once per year for an annual inspection. Fuel cells, however, are designed so that periodic maintenance such as filter replacement can be performed while operating, and therefore can be operated continuously for one full year.

4. Development of the "FP-100i" Popular-Type Phosphoric Acid Fuel Cell

To expand the usage of phosphoric acid fuel cells, there was a need to improve user convenience and to expand the range of environmental conditions under which installation was possible. Table 2 lists the specifications of the FP-100i. Aiming for a PR boost resulting from the positive environmental contribution and enhanced corporate social responsibility (CSR) associated with the installation of a fuel cell, so that the fuel cell may be installed at a site viewable by the general public, the entire system is finished with an in-line design whereby the inlet and exhaust ducts on the outer perimeter of the system are neither concave nor convex, and roof-mounted equipment is surrounded by fencing. Unlike the rigid image of a conventional power plant, a two-tone color palette of browns and whites provides a gentle image in harmony with the surrounding buildings and nature. The appearance of the FP-100i is shown in Fig. 3, and its features are described below.

4.1 Reduction of installation footprint and streamlining of onsite construction work

Fuel cells require the following types of peripheral equipment: waste heat treatment equipment, nitrogen

Table 2 FP-100i specifications

Rated output power	100 kW AC
Output voltage	3 ϕ3 W, 210 V/220 V
Output frequency	50 Hz/60 Hz
Electrical efficiency	42% (LHV) *Generating-end (Digester gas: 40%)
Thermal output (Either (1) or (2) can be selected from the column at right)	(1) High-temperature recovery type 50 kW (90 °C) Total efficiency: 62% (LHV)*
	(2) Medium-temperature recovery type 123 kW (60 °C) Total efficiency: 92% (LHV)*
Exhaust gas	NOx: 5 ppm or less (O_2: 0%) SOx, dust: Below detectable limit
Fuel consumption	City gas: 22 m^3 (Normal)/h (Digester gas: 44 m^3 (Normal)/h)
Operating method	Fully automated, grid-connected, independent operation
Dimensions	W2.2 × L5.6 × H3.4 (m)
Weight	City gas-fed type: 15 t (Digester gas-fed type: 16 t)

* LHV: Lower Heating Value. (Refer to Supplemental Explanation on page 240)

gas supply equipment, water treatment equipment, heat recovery equipment, an electric facility and a neutralizer. Previously, construction work for the installation, piping and wiring connections for this peripheral equipment was carried out onsite. With the FP-100i, however, this equipment has been integrally formed to reduce the size of the installation footprint and streamline onsite construction work. The size of the required installation footprint, including space for maintenance, has been reduced from 75 m^2 to 43 m^2 (Fig. 4). Further, although the waste heat treatment equipment to be mounted on the roof of the system is assembled onsite due to transportation restrictions, connectors are used for the wiring connections and the pipe laying work has been reduced to two lines in order to streamline the onsite construction work. In addition, because the peripheral equipment is mounted on the system, the size and weight of each device has been reduced. The main details are described below.

(1) Lighter-weight waste heat treatment equipment

Previously, the cooling water of the waste heat treatment equipment's condenser was the same as the cooling water that circulated inside the fuel cell package and that contained a small amount of phosphoric acid. By providing a heat exchanger in the circulation loop and separating the cooling water of the waste heat equipment from the cooling water inside the fuel cell package, corrosion due to the cooling water is prevented. As a result, the tube material used in the condenser could be changed from stainless steel to copper, and the thermal conductivity was improved. Additionally, the cooling fin pitch was reduced, a thin metal plate structure was used for the main body (casing) structure, and the condenser weight was reduced by about a factor of about two, from 1,350 kg to 600 kg. The lighter weight enables the condenser to be mounted on the roof, and realize an integrated structure.

(2) Reduction of nitrogen gas cylinders

Fig.3 Appearance of FP-100i

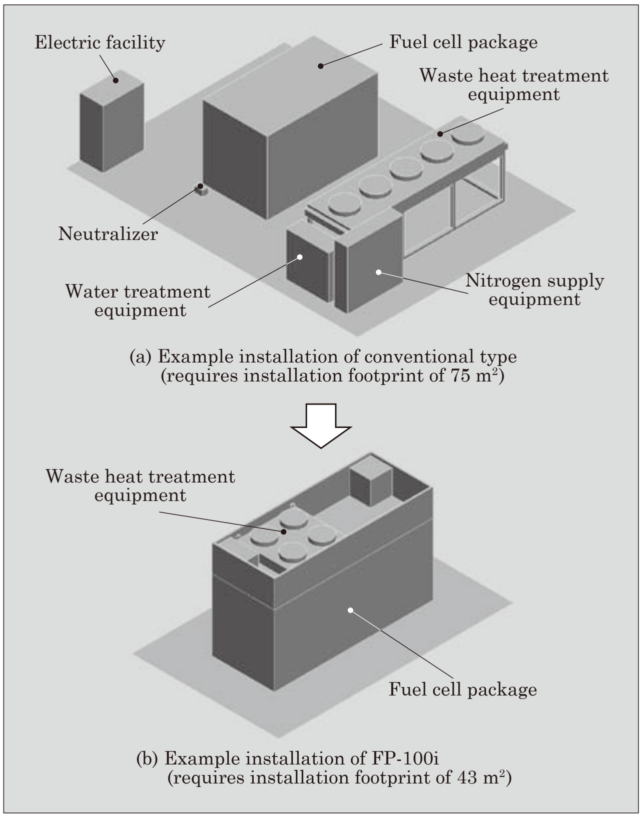
Fuel cells are provided with nitrogen equipment because, for safety reasons when the system is stopped, the flammable gas inside piping and devices must be replaced with nitrogen gas. Nitrogen gas cylinders (7 m^3/cylinder) were previously provided as 2 systems having a total of 6 cylinders (3 cylinders per system), but by optimizing the time for the flammable gas replacement, this has been reduced to 2 systems having a total of 4 cylinders (2 cylinders per system), and integrated. To verify operation after the reduction of nitrogen gas cylinders, demonstration tests were conducted using actual equipment, and it was verified that the gas inside the piping and devices had been replaced with nitrogen gas and that the gas concentration was reduced to sufficiently safe levels.

4.2 Support of low-temperature operation

An ambient temperature in the range of −5 °C to +40 °C had previously been required for installation of a fuel cell system, but with the FP-100i, the method of ventilation and device layout inside the fuel cell package have been redesigned to support ambient temperatures in the range of −20 °C to +40 °C. As a result, outdoors installation in cold climates is possible.

Based on thermal fluid analysis, the ventilation flow and the temperature distribution inside the fuel cell package were analyzed, and the ventilation air flow and device layout optimized. Actual equipment was used to verify the capability of the fuel cell system

Fig.4 Reduction of installation footprint and streamlining of onsite construction work



to operate continuously, without any trouble, in the temperature range from −20 °C to +40 °C. Specifically, as shown in Fig. 5, the fuel cell package is partitioned into a sub-component area provided with an inverter, pump, water treatment equipment, tank and the like, and a main component area provided with the cell tank and reforming system. Moreover, because the temperature is low during winter, an electric heater is provided at the inlet to the sub-component area to protect electric equipment and prevent the freezing of equipment that handles water.

4.3 Improved Transportability

Because marine transport would be necessary in order to popularize the usage of fuel cells abroad, Fuji Electric developed the following two technologies for improved transportability.

(1) Elimination of power supply for warming during transit

In a phosphoric acid fuel cell, phosphoric acid is used as the electrolyte in the cell stack. Because a high concentration of phosphoric acid will freeze at room temperature, in the past, a generator or the like was used to supply electricity to an electric heater that kept the phosphoric acid warm during transit. However, because of the difficulty of retaining heat during transportation by ship, there was a desire to eliminate the need for keeping the phosphoric acid warm. Thus, Fuji Electric developed a method for preventing freezing by lowering the concentration of phosphoric acid during transit. This method was demonstrated on actual equipment and makes possible transportation without the need for warming.

(2) Development of protective material (shock absorber)

Fuel cell systems are designed to be able to withstand vibrations of up to 1 G during transportation. However, when being loaded onto a ship in port, mechanical shocks in excess of 1 G may be applied. Therefore, protective material (a shock absorber) is attached to the bottom of the fuel cell system so as to be able to withstand impacts of up to 3 G.

4.4 Improved earthquake resistance

In order to improve earthquake resistance, the strengths of the fuel cell system stand and stack were analyzed during the planning stage, and those results were reflected in the design. Then, a vibration test was performed in which actual equipment was mounted on a vibration tester whereby the waveform of the vibrations was equivalent to the actual seismic vibrations of the Niigata Chuetsu Earthquake, and after the vibration test, the fuel cell system was confirmed to be capable of generating power without problem.

5. Future Outlook

By leveraging their characteristic feature of a hydrogen fuel source, Fuji Electric's phosphoric fuel cells help to advance development for new applications which, in the past, had mostly been implemented as co-generation applications fueled by city gas. Figure 6 is an explanatory diagram showing new applications for phosphoric fuel cells, the main details of which are described below.

5.1 Fuel cells that utilize pure hydrogen and by-product hydrogen (refineries, chemical plant by-product gas)

Fuel cells that utilize pure hydrogen or by-product hydrogen do not require that the fuel be reformed, and are supplied directly with hydrogen fuel to generate electrical power. By using pure hydrogen (99.9% high concentration hydrogen) generated from a caustic soda factory or the like as fuel, a system with even higher electric efficiency can be constructed. This is because the waste hydrogen emitted from the fuel cell is not exhausted directly, but instead, is returned to the fuel cell stack inlet and recycled so that a high rate of hy-

Fig.5 Layout and ventilation flow inside fuel cell package

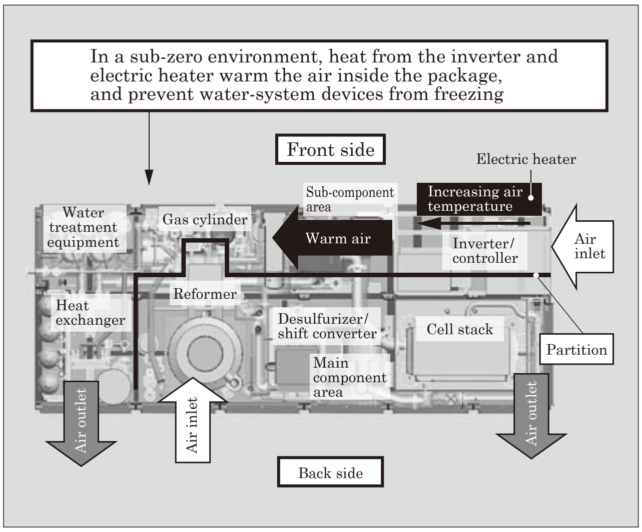


Fig.6 New applications for phosphoric acid fuel cells

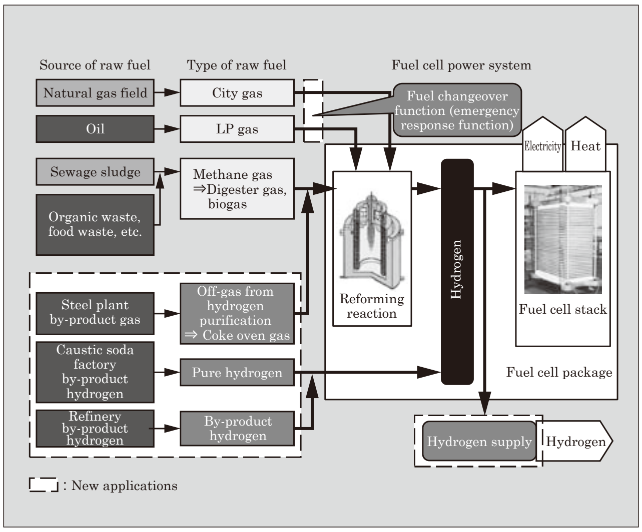


Fig.7 Power supply methods for normal operation and emergency operation

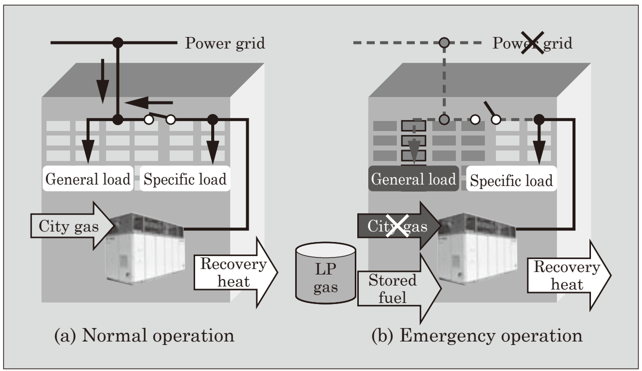
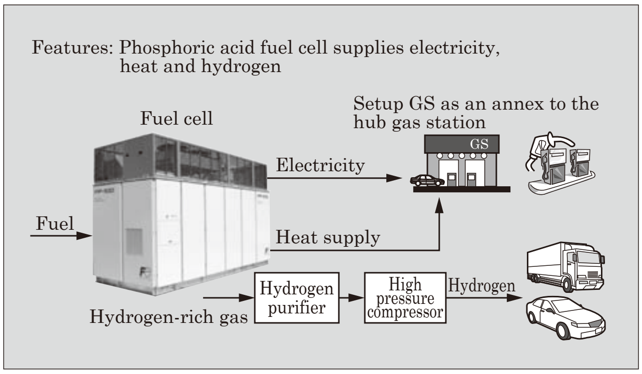


Fig.8 Fuel cell equipped with hydrogen supply function



drogen utilization can be realized. A system with high electric efficiency of up to 48% (at the fuel cell stack output) can be constructed, and compared to the case in which a boiler is used, the use of pure hydrogen results in a CO_2 reduction effect that is 1.6 times larger.

5.2 Fuel cell equipped with emergency response function

In the event of an emergency or the like where the electricity or city gas is shut off, power is typically supplied by an emergency power generator. By installing fuel cells equipped with an emergency response function at disaster prevention centers and the like, power and heat will be supplied normally, and during an emergency, the fuel can be switched from city gas to stored LP gas so that power generation can continue and power and heat can be supplied.

The heating value of LP gas is approximately twice that of the city gas and therefore the reforming conditions for making hydrogen are different. Nevertheless, the fuel cell generates power once fuel has been reformed into hydrogen by the fuel reforming system, and power generation can continue without stopping. Moreover, when operating with LP gas as the fuel, the output is 70 kW, and a 50 kg gas cylinder will be enable electricity to be supplied for approximately three hours. Figure 7 shows the methods of power supply during normal operation and emergency operation.

5.3 Fuel cell equipped with hydrogen supply function

Fuel cells equipped with a hydrogen supply function are tri-generation systems capable of supplying not only electricity and heat, but also hydrogen. During the daytime, electricity and heat from co-generation are utilized, and during the nighttime when the load is less, the power output is decreased and excess hydrogen production capacity is harnessed to extract and supply hydrogen gas. These types of fuel cells are suited for usage at hydrogen stations necessary for fuel cell-powered vehicles, business offices that require small amounts of hydrogen, and so on. Figure 8 shows a schematic representation of these applications.

6. Postscript

Because fuel cells are systems that contribute to curbing global warming and protection of the global environment, efforts to promote their popularization and widespread usage will have a positive impact on society. To promote the usage of fuel cells, Fuji Electric intends to expand the range of applications further and to improve user benefits.

The authors express thanks to the relevant organizations and users for their guidance and cooperation thus far, and ask for increased understanding and support in the future.