Field Test Results for a 250-kW-Class Polymer Electrolyte Fuel Cell Cogeneration System

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Abstract

We present field test results for a 250-kW-class polymer electrolyte fuel cell (PEFC) cogeneration system that includes an absorption refrigerator. The cogeneration system was field tested from November 2000 to May 2003 and the PEFC was operated for a total of 5026 hours, generating 624 MWh. Electrical efficiency of 34%, thermal efficiency of 42%, and total efficiency of 76% were obtained for the PEFC. A test room was air-conditioned at around 20°C by circulating the cold water cooled by the absorption refrigerator using low-temperature-level hot water (below 75°C) warmed by heat from the PEFC.

1. Introduction

Power consumption in telecommunication systems has been increasing drastically because of the rapid increase in the amount of data transmitted over networks with the progress in multimedia communications. On the other hand, social concern about global environmental problems, especially global warming, has been growing, and we must make an effort to reduce greenhouse gas emissions. Therefore, the development of energy systems that generate power efficiently and cleanly is becoming more important for telecommunications.

Based on this background, NTT is vigorously promoting the introduction of clean energy sources, including natural energy sources like solar and wind power, and taking steps to reduce the power consumption of telecommunications systems. In particular, there are strong expectations to implement fuel cell systems for telecommunications power systems because exhaust heat as well as electricity from the fuel cell is utilized: the former for cooling the telecommunications equipment room via an absorption refrigerator and the latter for powering the switching equipment.

NTT field-tested 200- and 100-kW-class phosphoric acid fuel cell (PAFC) cogeneration systems that included an absorption refrigerator from 1995 to 1999 [1]-[4]. Exhaust heat from the PAFC was used to make hot water and/or steam, a conventional type of an absorption refrigerator was operated using 85–90°C hot water, and a newly developed absorption refrigerator was operated using 50–70°C hot water and 160°C steam. NTT has also developed some new technologies for a PAFC cogeneration system, including a multi-fuel system that can use alternative fuels (such as liquid petroleum gas) and a deterioration evaluation method for the reformer and cell stack. These developed systems and technologies have already been installed inside and outside buildings and are still working well.

As the next step in developing fuel cell cogeneration systems, NTT cooperatively field-tested a 250-kW-class PEFC cogeneration system that includes an absorption refrigerator with Ebara Co. and Ebara Ballard Co. from November 2000 to May 2003 [5]-[8]. The test unit was made by Ballard Generation Systems Inc. in Canada, and seven other units of the same

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type were installed in Europe (5 units), the United States (1 unit), and another site in Japan (1 unit). Except for the two in Europe, the field tests for these PEFC units have already finished.

A PEFC is expected to have a high energy density and low manufacturing cost compared with a PAFC. Furthermore, it operates at a low temperature of around 80°C, so a short start-up time is also expected. However, due to its low operating temperature, its thermal output can heat water to at most 75°C, which is too low to operate a conventional absorption refrigerator efficiently. Therefore, a new absorption refrigerator that can use this low-temperature hot water efficiently was developed by Ebara Co. by improving the heat exchanger.

This paper summarizes the field test results for the 250-kW-class PEFC cogeneration system.

2. System configuration and specifications

The test facility for the field test system in the NTT Musashino R&D Center in Tokyo is shown in **Fig. 1**. The 250-kW-class PEFC was installed in a building and connected to an absorption refrigerator outside the building. Three air conditioners (fan coil units) were installed in a test room next to the room where the PEFC was installed. The configuration of the field test system is shown in **Fig. 2**. Town gas*1 was supplied to the PEFC, which outputs three-phase AC power at 400 V. The 400-VAC power was boosted to 3300-VAC power and connected to the commercial power supply. The 3300-VAC power was supplied to loads in another building in the R&D Center. Thermal power from the PEFC was used to operate the absorption refrigerator by warming circulating water and delivering it to the absorption refrigerator. Using the warmed water from the PEFC, the absorption refrig-

*1 Town gas here is primarily made from natural gas and its main constituent is CH_4 (about 85%).

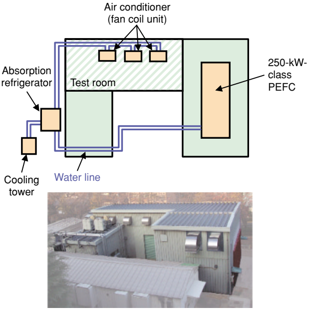

Fig. 1. Test facility for the PEFC cogeneration system.

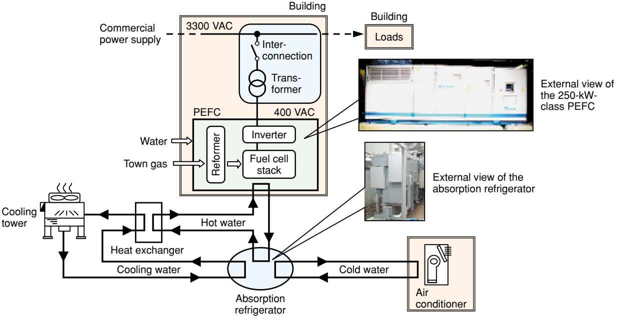

Fig. 2. Configuration of the PEFC cogeneration system.

Table 1. Specifications of the PEFC.

Fuel	Natural gas
Rated power	212 kW
	(Commercial target) 250 kW
Rated voltage	400 VAC (three-phase)
Rated frequency	50 Hz
Maximum temperature of water produced	75°C
Efficiency (LHV)	Electrical: 34% Thermal: 38% Total: 72%
	(Commercial target) Electrical: 40% Thermal: 40% Total: 80%
Size	7.3 m (L) 2.4 m (W) 2.6 m (H)
Weight	21 tons

Table 2. Specifications of the absorption refrigerator.

Capacity		176 kW
Hot water	Temperature	73.9°C (inlet) 71.1°C (outlet)
	Flow rate	1220 *l*/min
	Thermal power into refrigerator	238 kW
Cooling water	Temperature	30.5°C (inlet) 35.4°C (outlet)
Cold water	Temperature	12°C (inlet) 7°C (outlet)
	Flow rate	500 *l*/min
	Cold thermal power outside refrigerator	176 kW
COP		0.7
Size		3.63 m (L) 1.35 m (W) 2.18 m (H)
Weight		7.0 tons

erator generated cold water, which was supplied to an air conditioner for cooling air. A cooling tower was connected to the absorption refrigerator to cool the refrigerant in the absorption refrigerator by circulating water. Field test data and alarm signals were automatically sent to a personal computer in an office building via a local area network (LAN).

Table 1 shows the specifications of the PEFC. Natural gas is used as the fuel, and oxygen in the air is used as the oxidant. To increase the output power of the cell stack, both natural gas and air are pressurized by compressors in the system. Rated power is 212 kW and the target for a commercial system is 250 kW. The electrical and thermal efficiency targets are both 40% (LHV[*2]). Thermal power from the PEFC can make hot water with a temperature of 75°C.

Table 2 shows the specifications of the new absorption refrigerator based on the water-lithium bromide (LiBr) system. Its capacity is 176 kW and cold water (7°C) can be made by supplying hot water (73.9°C) at a flow rate of 1220 *l*/min. COP[*3] is 0.7, which is a high value.

3. Field test results

3.1 Characteristics of PEFC

Figure 3 shows cumulative operation time and generated power of the PEFC each month from November 2000 to May 2003. The PEFC was operated for a total of 5026 hours, generating 624 MWh, so the average output power in operation was 124 kW.

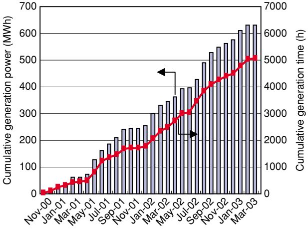

Fig. 3. Cumulative operation time and generation power of the PEFC.

The relationships between electrical power and electrical efficiency, thermal efficiency, and thermal power of the PEFC obtained on the same day are shown in **Fig. 4**. Here, the thermal power refers to the thermal energy carried away by the circulating hot water per unit time, and the thermal efficiency refers to the ratio of thermal power to the chemical energy of the town gas supplied to the PEFC per unit time.

*2 LHV: Lower heating value. The potential energy in a fuel if the water vapor from the combustion of hydrogen is not condensed.

*3 COP: Coefficient of performance. The COP of a refrigerator represents its efficiency and is defined as the fraction of the desired output divided by the required input of the refrigerator.

The electrical efficiency was an almost constant value of about 34% between 100 and 212 kW of electrical output power.

The thermal power and thermal efficiency increased almost linearly as the electrical power increased, and maximum values of 260 kW and 42% were observed at 212 kW of electrical power. Thus, total efficiency, i.e., the sum of electrical and thermal efficiencies, was 76% at 212 kW.

Figure 5 shows the effect of ambient temperature on electrical efficiency for 212 kW of electrical power, which includes ten days of data measured every minute. The electrical efficiencies decreased as the ambient temperature increased when the ambient temperature was above 18°C. This decrease in electrical efficiency depends mainly on two factors. First, the air compressor, which uses a burner running on town gas, requires more town gas to compress more air as the ambient temperature becomes higher because the density of air decreases as its temperature increases. The second factor is that more electrical power must be supplied to the cooling fans of the PEFC as the ambient temperature increases to maintain the temperature inside the PEFC.

We also examined the PEFC's effect on the environment by chemically analyzing exhaust gases from the PEFC. Some toxic gases, such as NOx, SOx, CO were detected, but they were all below permissible levels.

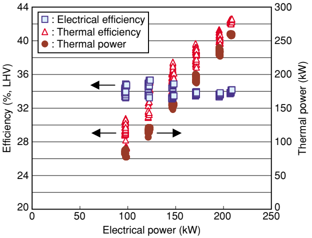

Fig. 4. Relationships between electrical power and electrical efficiency, thermal efficiency, and thermal power.

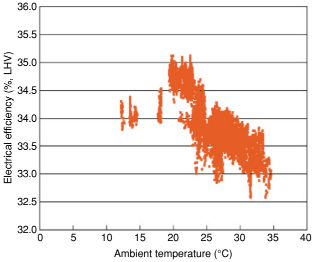

Fig. 5. Relationship between ambient temperature and electrical efficiency of PEFC operated at 212 kW.

3.2 Characteristics of PEFC cogeneration system

The absorption refrigerator requires hot water at 73.9°C to achieve the values shown in Table 2. Experimental results for the inlet versus outlet hot-water temperatures (T_1 and T_2) of the PEFC when the hot-water flow rate was 1200 *l*/min and the PEFC generated 200 and 212 kW of electric power are shown in **Fig. 6**. T_2 rose linearly with T_1 for both power levels. T_2 reached 75.0°C (74.8°C) when T_1 was 72.5°C for 212 kW (200 kW) kW of electrical power. These results confirm that the PEFC could output the thermal power required by the absorption refrigerator, and we operated the absorption refrigerator under the condition that the PEFC was running at 200 kW or

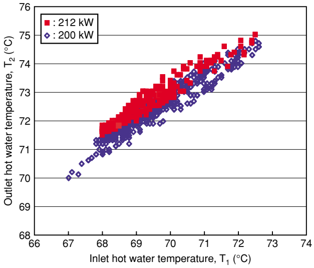

Fig. 6. Inlet hot-water temperature (T_1) versus outlet hot-water temperature (T_2) of the PEFC when the hot-water flow rate was 1200 *l*/min and the PEFC generated 200 or 212 kW of electrical power.

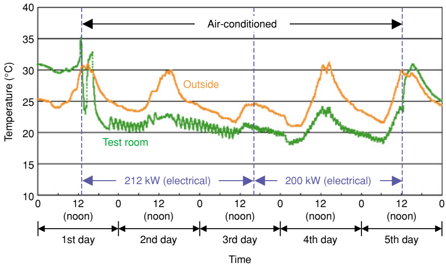

Fig. 7. Changes in test room temperature when the air-conditioner was operating.

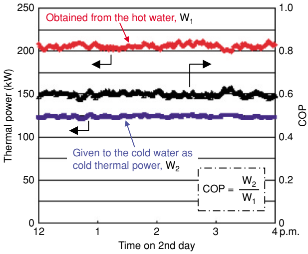

Fig. 8. Test operation data for absorption refrigerator on the 2nd day.

Table 3. Measured characteristics of absorption refrigerator operated below its rated capacity from 12 noon to 4 p.m. on the 2nd day.

Hot water	Temperature	72.2°C (inlet) 70.2°C (outlet)
	Flow rate	1160 l/min
	Thermal power into refrigerator	205.7 kW
Cooling water	Temperature	30.3°C (inlet) 34.1°C (outlet)
Cold water	Temperature	10.6°C (inlet) 7.0°C (outlet)
	Flow rate	500 l/min
	Cold thermal power outside refrigerator	123.4 kW
COP		0.601

above.

We tried to air-condition the test room shown in Fig. 1 at about 20°C. Changes in the test room's temperature and outside temperature for five days are shown in **Fig. 7**. The electrical power was initially set at 212 kW and changed to 200 kW on the third day. The test room was air-conditioned at about the set value of 20°C. The room's temperature was strongly affected by the outside temperature because the room's heat insulation was not so good, and the fluctuation in the test room's temperature was due to the fluctuation in the cold-water temperature from the absorption refrigerator.

Figure 8 shows operation data for the absorption refrigerator measured from 12 noon to 4 p.m. on the second day. It plots the COP and changes in the thermal power that the absorption refrigerator obtained from the hot water and that the absorption refrigerator gave to the cold water as cold thermal power. In this time range, the absorption refrigerator was operated at less than the rated capacity. Average values of the results obtained from Fig. 8 are shown in **Table 3**. The inlet hot-water temperature (72.2°C) was 1.7°C lower and the thermal power given to the absorption refrigerator (205.7 kW) was 14% less than the specified values. Under this condition, cold water was cooled to 7.0°C and the COP was 0.601. This COP value satisfies the specifications of the absorption refrigerator operated at less than its rated capacity. Therefore, if the capacity of the cooling loads of the room were equal to the rated capacity of the absorption refrigerator, a COP of 0.7 could be obtained constantly.

3.3 Maintenance for the PEFC

The PEFC needs regular maintenance such as changing the ion exchange resin for making pure water, changing the oil for the air-pressurizing system, changing the filter of the gas compressor, and calibrating the CO sensor for gas chromatography. The current interval between maintenance sessions is from one week to two months. Furthermore, the PEFC sometimes experienced some trouble in this field test: a pump, control valve, and thermocouple did not work well, so we replaced them with new ones. For practical use, we must improve the reliability of the PEFC so that the maintenance interval can be increased and unexpected trouble will occur less frequently.

4. Conclusions and future plans

We observed electrical efficiency of 34%, thermal efficiency of 42%, and total efficiency of 76% for the PEFC and a test room was air-conditioned at about 20°C by using an absorption refrigerator. These results show that a PEFC cogeneration system that includes an absorption refrigerator is promising for telecommunication systems. We are now considering the required system cost, running cost, maintenance cost, system capacity, and lifetime for practical use from an economical viewpoint.

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