UDC 621.311.25:[621.352.6:546.185-325]

DEVELOPMENT OF DISPERSED FUEL CELL POWER PLANTS

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1. FOREWORD

The basic technology for development of dispersed fuel cell power plants was completed with the successful trial operation from 1987 to 1988 of the two 1 MW power plants planned by the New Energy and Industrial Technology Development Organization (NEDO) in the Moonlight Project which started in 1981.

Fuji Electric has clarified the various development problems and development targets for future large plants and has studied practical scale plants to solve these problems based on these results. This paper introduces the details and development trend of plants based on the results of these studies.

First, the plan for this plant was based on the following basic concept:

(1) Application: Dispersed power plant with urban area as the ultimate consumer area
(2) Economy: Same as existing system with the advantages of dispersed installation added.
(3) Operation: Grid connected operation. Operation by electric output control by programmed daily load pattern centered about weekly start and stop (WSS). Automatic starting and stopping.
(4) Fuel: LPG (city gas)
(5) System: Extremely simple with good controllability.
(6) Environmentability: Little pollution (noise, vibration, exhaust gas)
(7) Compactness: Extensive compacting aimed at reduction of area, simplification of shipment, reduction of onsite cost, and shortening of construction time.
(8) Waste heat: Utilization (to control electric power followed by heat).
(9) Plant configuration: Module type (plant of the required capacity built by combining standard units). Module capacity 5 MW.

The main development problems for early development of a large fuel cell power plant are:

(1) Development of a large high-performance cell (1 m^2 class)
(2) Development of a large reformer
(3) Development of pressurization and power recovery systems
(4) Design and development of a compact plant

Table 1 Basic specification of 5 MW fuel cell power plant

Rated output		5 MW at AC generating end
Net efficiency		42.2% HHV basis
Type		Phosphoric acid fuel cell
Fuel cell operating temperature		200°C
Fuel cell operating pressure		6 $kg/cm^2 g$
Fuel cell coolant		Water
Output voltage		6,600 V
Output range		30~100%
Emission at rated operation	NOx	max 10 ppm
	Acoustic	max 55 dB (A)
Start-up time (warm)		within 3 hours
Load change rate		20%/minute
Fuel		City gas (Natural gas)
Waste Heat		Recover to utilize

To solve these development problems, element research was conducted in cooperation with the Kansai Electric Power Co., Inc. An order for design of a 5 MW class trial plant to be run by NEDO and the Technology Research Association for PAFC Power Generation System was received and design was initiated.

2. BASIC SPECIFICATIONS AND CONFIGURATION OF PLANT

The basic specifications of the 5 MW fuel cell power plant are shown in *Table 1*. Its system flow diagram is shown in *Fig. 1*.

The rated output is 5 MW and the output range is 30 to 100%. Net efficiency is 42.2% on an HHV basis. A motor driven compressor is used in air pressurization. Operation and control of the entire system is stabilized and the start-up time is shortened and load following ability is improved by using a system which recovers the power by exhaust gas turbine.

The perspective view of the 5 MW plant is shown in *Fig. 2*.

Since the basic policy of the dispersed fuel cell power plant installation plan was ample incorporation at urban areas with existing equipment, efforts were made to make the plant compact enough to be installed at former sub-

Fig. 1 System flow diagram of 5 MW fuel cell power plant

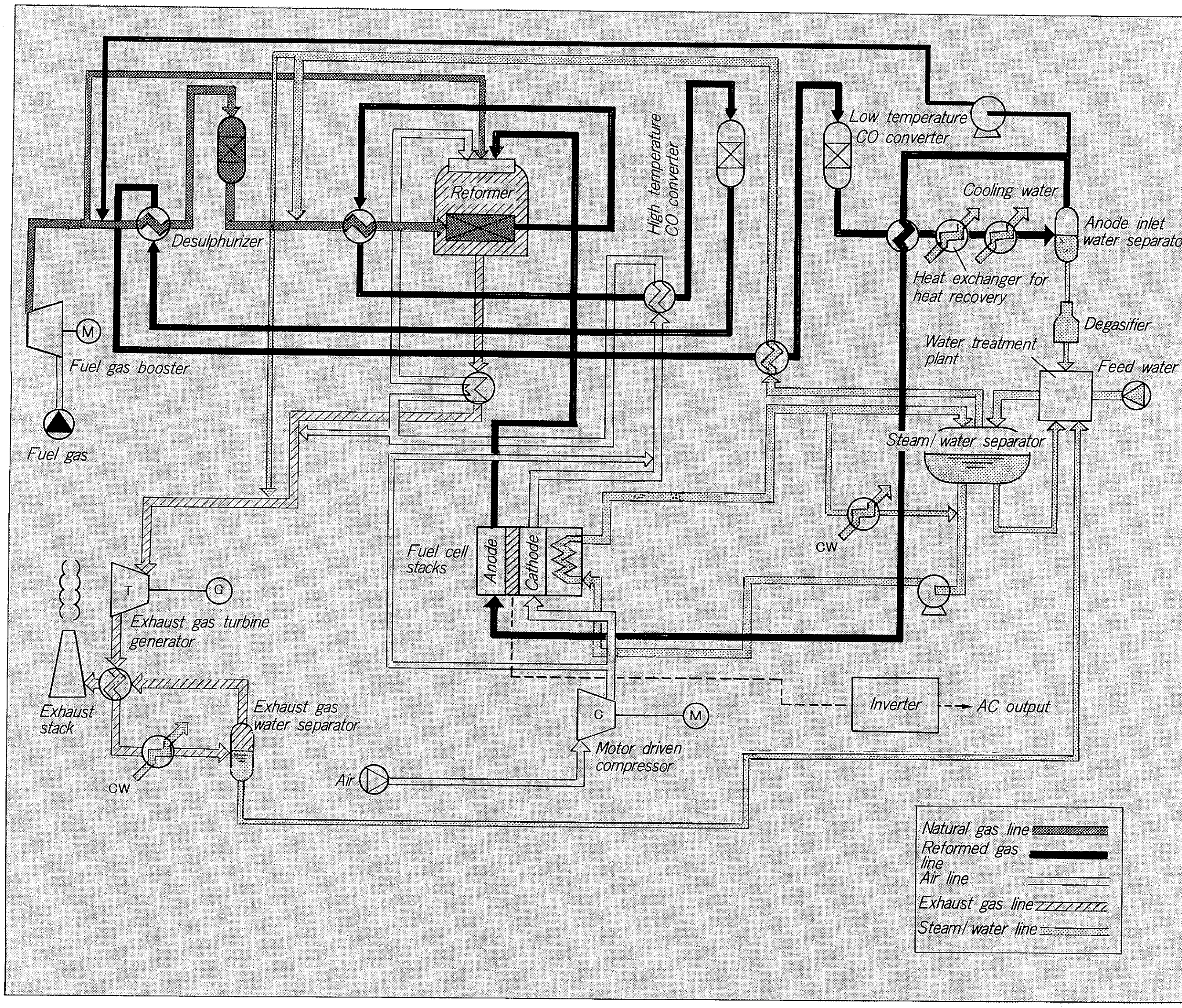
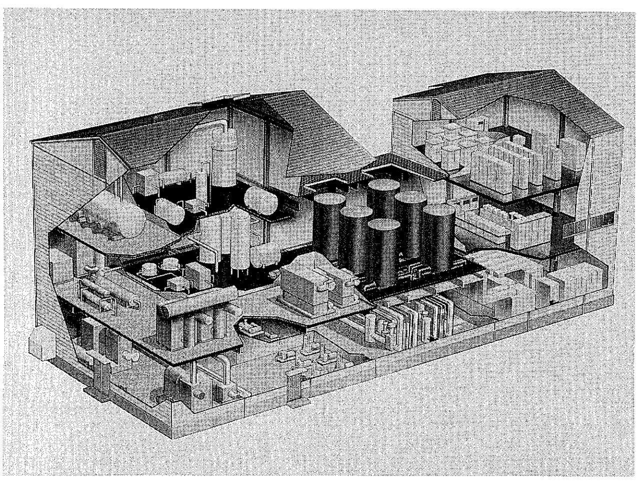


Fig. 2 Perspective view of 5 MW plant



station sites and the limited area and space under buildings.

Next are exhaust, waste water, noise, vibration, appearance and other environmental conditions. Good compatibility with the surrounding environment is necessary. Happily, a fuel cell power plant discharges little atomospheric pollutants and is compatible with the environment. Here, noise and appearance were taken into account and an indoor type was made the rule.

The time schedule for 5 MW power plant construction is shown in *Fig. 3*.

Naturally this is planned by shortening the period from design to pre-use inspection as much as possible. In particular, the installation and test period at site is shortened. This is done to shorten the installation work time in urban areas and to raise the quality level by manufacturing and testing the equipment in the factory where facilities are available, considering the equipment to be installed in urban areas.

Table 2 Specification of fuel cell stack for 5 MW plant

Output	859 kW per stack
Cell voltage	0.746 V
Current density	300 mA/cm²
Operating pressure	6 kg/cm² g
Mean operating temperature	200°C
Area of electrode	8,000 cm²
Configuration	Ribbed substratum
Coolant	Water

Fig. 3 Time schedule for power plant construction

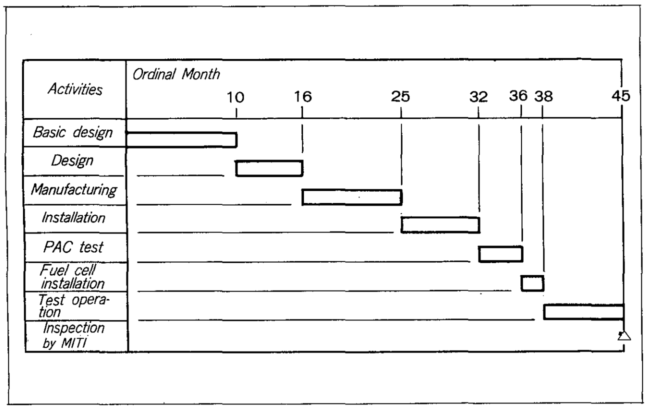
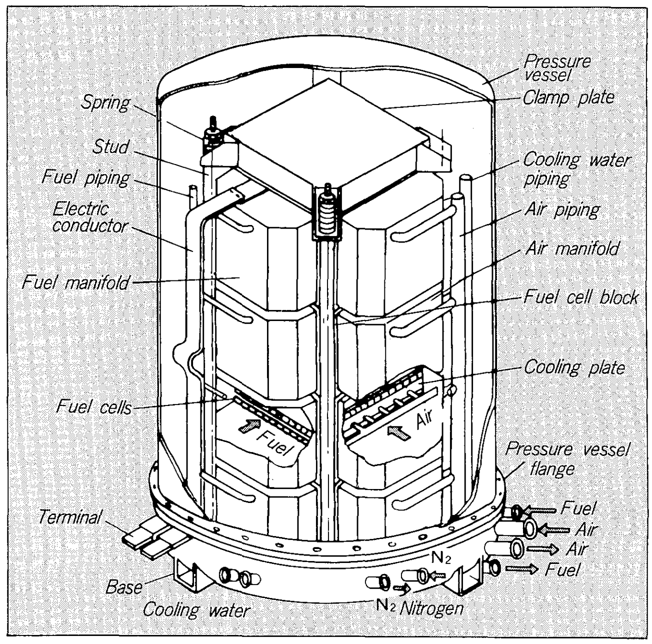


Fig. 4 Configuration of fuel cell stack



3. MAIN COMPONENTS

3.1 Fuel cell

Development of a large high-performance cell permits generation of 5 MW of electric power with six stacks. From the standpoint of equal distribution of the gas, the stacks are divided into two trains of three stacks and connected in a 3-series 2-parallel configuration. The development target specifications of the fuel cell stack are shown in *Table 2*. The configuration of the fuel cell stack is shown in *Fig. 4*.

The items which were especially important in achieving the development target specifications above are described below.

3.1.1 Development of high power density electrode

A cell power density of 0.14 W/cm² was achieved with the 1 MW fuel cell plant of the Moonlight project. However, since this power density is unsuitable from the standpoint of cost and compactness, development aimed at a power density improvement of approximately 1.6 times or more was advanced.

3.1.2 Development of large fuel cell

With the 1 MW fuel cell plant of the Moonlight project, a fuel cell with an electrode area of 3,600 cm² class was developed and cell power reached an operating record of approximately 0.5 kW. However, since this area is unsuitable for practicalization of a high capacity plant from the standpoints of cost and compactness, a high power density electrode with a 1 m square area of 8,000 cm² class, which is considered to be the maximum, was developed.

3.1.3 Improvement of fuel cell life and other reliability

Improvement of cell reliability becomes increasingly important as the cell area and stacking become larger. Therefore, in cell substrate design, the worst case is assumed and the cell is constructed to allow replacement in cells between cooling plates. Moreover, to cope with changes of the cell phosphoric acid retaining condition, which varies with long-term operation and various operating conditions, the cell was constructed to have a phosphoric acid retaining capability of at least 10,000 hours.

Cell reliability was confirmed by life confirmation and accelerated life tests conducted with a small cell and a large fuel cell short stack manufactured by changing the design and manufacturing conditions.

3.1.4 Development of large, high power fuel cell stack components

The cooling plates and clamp which are major components of a fuel cell stack besides the cell were developed.

Because the size and power of the cell are increased, the heat dissipation rate required per cooling plate is about 3.6 times that of the 1 MW fuel cell of the Moonlight Project. However, from the standpoint of compactness, the cooling plates must be as thin as possible.

When the clamping force is increased by increasing the area of the cell, the deflection of the clamp becomes larger. However, from the standpoints of compactness and cost reduction, the deflection was kept small and the compression stress was equalized without increasing the plate thickness and the prescribed compression stress was obtained in various operating states.

3.1.5 Development of large, high power fuel cell stack stacking technology

To stack large, high power cells, not only must the cell and stack components described above be developed, but the compression stress distribution in the cell generated by the dimensional difference in plane and increase of internal resistance by this when these parts are assembled must be prevented and generation of deviation between stack parts and destruction of the parts when the stack was clamped due to the difference of the in-plane stack height must be prevented.

When the amount of hydrogen and air supplied to each part of the cell varies considerably, a sufficient amount of these reaction gases may not be supplied to some parts and the cell characteristics will drop and the cell may deteriorate due to catalyst sintering by partial heating and corrosion of the catalyst support. These technologies were developed by fabricating a model and 1/4 stack.

3.2 Reformer

The performance and functions required of a fuel reformer for a fuel cell are discussed below.

First is compactness. For dispersed installation, site conditions require compactness of a power plant. The shape and dimensions of the reformer must also match this.

Second is the load change speed. Whereas a reformer for the chemical industry is operated at almost a constant load, since the electric output change speed for a fuel cell is large, the reformer must change its hydrogen production rate to follow this change.

Third is stable combustion and efficiency improvement. The burner must be capable of lean burning by pressurized fuel cell anode leaving gas and cathode leaving gas. Minimization of the amount of heat applied from the outside for reformation use in the reformer itself also contributes directly to the thermal efficiency of the plant.

Fourth is low NOx. With fuel cell leaving gas, 10 to 20 ppm can be achieved. This is worthy of mention as the quality of the environmentability of the fuel cell power plant.

The following three main types were trial operated or a test report was announced as pressurized reformers with characteristics suitable for a dispersed fuel cell power plant:

(1) Mono-tube type
(2) Multi-tube type
(3) Fluidized bed combustion type

Of these, the mono tube type was used at this 5 MW generating plant for the following reasons.

As yet there is no record of combination of a reformer of this type with a fuel cell, but with EPRI assistance, Haldor Topsoe International A/S has built a 1.25 MW reformer test facility in Houston, Texas in the United

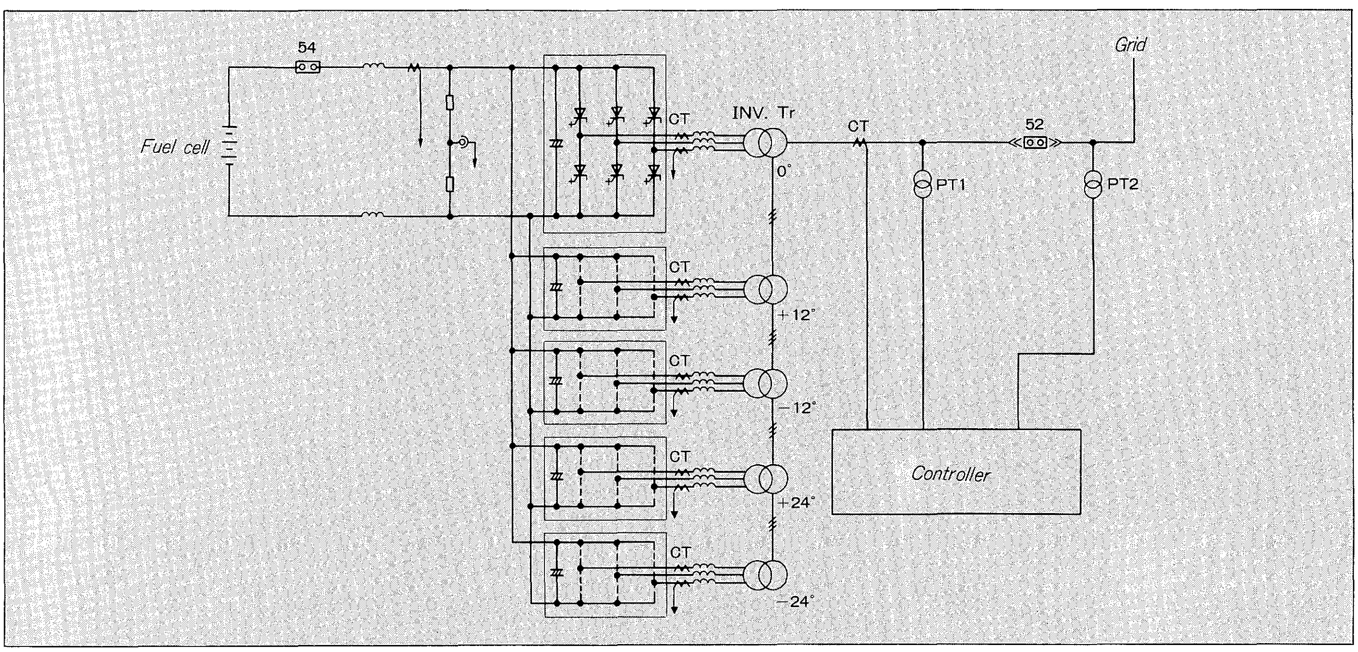
Table 3 Specification of reformer

Type	Mono-tube type
Hydrogen production rate	3,652 m^3 N/h
Fuel	City gas (natural gas)
Fuel for burner	Anode leaving gas

Table 4 Specification of inverter

Type		Self exciting inverter
Capacity		5,000 kVA
Input	Voltage	DC 1,074 V
	Current	DC 4,800 A
Output	Number of Phase	3
	Frequency	60 Hz
	Voltage	6.6 kV

Fig. 5 Basic diagram of inverter



States and has ended trial operation of more than 4,000 hours.

Regarding its excellent characteristics, according to the test report, the load change time is 3 hours 15 minutes from the cold condition to 25% load and 42 seconds from 25% to 100% load. As for the load change, a heat cycle test in which 100% and 25% load change was performed every hour during the day for one week, 25% constant load operation was performed at night, and the facility was completely stopped over the weekend was conducted for more than 14 weeks and its results were proven. Concerning compactness, the reformer is a slim cylindrical stand-alone type with a small footprint. This type best satisfies the requirements previously mentioned.

The design specifications of the reformer are shown in *Table 3.*

3.3 Inverter

A newly developed high-capacity GTO applied for the inverter element. Control reliability was improved substantially by using an optic fiber cable that is not disturbed by noise for inverter signal transfer. The basic specifications of the inverter are shown in *Table 4*. Its basic configuration is shown in *Fig. 5*.

The DC power output from the fuel cell is supplied to a power inverter through a DC high speed circuit breaker with short circuit protection and a DC smoothing circuit consisting of a DCL and capacitor to suppress the cell current fluctuations. The power converter uses GTO and is made up of five voltage type inverter bridges.

The bridges are connected at the AC side by transformers and a 30-phase composite multiple output is obtained and harmonics are reduced by a 5-multiple 6-phase inverter. A detector for control and protection is connected to this composite output. The output is supplied to the power grid through an AC circuit breaker which provides short circuit protection for the grid.

4. CONCLUSION

The basic concept, specifications, features of the main components, and the layout of a 5 MW dispersed fuel cell power plant were described above.

More power will be poured into practicalization in the future.

Finally, the authors wish to thank the concerned parties for their guidance and assistance.