ABSTRACT

A 25 kW class SOFC power generation system development program was initiated by four companies: Westinghouse Electric Corporation who is an American manufacturer, The Kansai Electric Power Company, Tokyo Gas Company and Osaka Gas Company who are the Japanese UTILITIES, as a internationally jointed project in early 1989. After three years system development and manufacture, the system passed through the inspection done by Ministry of International Trade and Industry of Japan to certify the generation system to be in conformity with Japanese Technical Standard for Thermal Power Plant, and was installed in the test site (near Kobe, Japan) of The Kansai Electric Power Company. Installation and system checks were completed within three weeks and verification testing was initiated in the last week of February 1992. Operation went smoothly with stable operation at nominal output power of 36 kW dc and at a high fuel utilization of 85%. System details and interim results of verification testing may be reported in this proceedings.

INTRODUCTION

A 25 kW SOFC power generation system was manufactured by Westinghouse for the UTILITIES, a consortium in Japan of The Kansai Electric Power Company, Tokyo Gas Company and Osaka Gas Company. After a short period of operation at the place of manufacture near Pittsburgh, Pennsylvania, the system was transported by truck and air freight to the Rokko Test Center for Advanced Energy Systems (near Kobe, Japan) of The Kansai Electric Power Company. Installation and system checks were completed within three weeks and verification testing was initiated in the
last week of February 1992.

OUTLINE OF SYSTEM SPECIFICATIONS

Specifications for this system are shown in table 1. Expected efficiency is about 45% (gross dc output/HHV) with gross system output of 36 kW dc at nominal conditions. The gross peak system output is estimated to be 44 kW dc, one of the largest capacity SOFC system ever operated.

SYSTEM CONSTITUTION

The system is contained in a compact enclosure with a footprint of 5.8 square meters as shown in Figure 1. The system consists of two independently operable dc modules. Each dc module contains 576 tubular solid oxide fuel cells of 500 mm active length. A module is composed of 7 system elements: the Air Supply System; the SOFC Generator; the Prereformer; the Fuel Supply System; the Cylinder Gas Supply System; the DC Dissipator; and the Control System as shown in Figure 2.

The supply of process air to each SOFC module is provided by a motor-driven centrifugal blower. Before entering into the generator, inlet air is pre-heated in the exhaust gas heated recuperator and in the electric air preheater which is used as a trim heater to adjust the air inlet temperature during part load operation and as the heat source during startup.

A conceptual diagram of the generator module is shown in Figure 3. The air is fed into the cells from the top of the generator through thin tubes inside each cell. Air passing through the tube contacts the cell at the closed bottom end and flows upward along the surface of the air electrode. The fuel is fed into the exhaust gas heated prereformer integrated with the SOFC generator module at the bottom, and is partially reformed in it before entering the cell stack. Remaining unreformed fuel is completely reformed within the cell stack. The steam required for reforming is provided to the prereformer by recirculating a portion of the steam rich reacted fuel gas (spent fuel) from the cell stack, so that externally supplied water or steam is not required to support reformation or inhibit carbon deposition. Unreacted fuel burns in the combustion zone in the generator to provide heat for inlet air.

The fuel is a desulfurized city gas (predominantly methane) of 200 mm water gauge normal distribution pressure, and is compressed to approximately 2 atm gauge pressure by the fuel compressor to permit ejector recirculation of spent fuel for the prereformer.

The Cylinder Gas Supply System consisting of 20 hydrogen gas cylinders and 36 hydrogen mixed nitrogen gas cylinders
provides purge gas and hydrogen gas (which is the fuel during the startup cycle and normal cool down) to the SOFC generator. Each cylinder contains 7 normal cubic meters of gas at 150 kg/cm² pressure.

The dc dissipator, which houses power electronics and dissipative resistors, modulates the current flowing through resistors by chopping the dc current into current pulses, so that the output energy of this system is consumed without connecting to the electric utility grid.

The control system is sophisticated and permits completely automatic unattended normal operation and an automated system start up. This computer based control system consists of a programmable controller, input/output modules and an operator interface. A personal computer is used for the operator interface as shown in Figure 4, and is connected to the programmable controller to view module and system status, to report alarm conditions, and to display setpoints, process variables, and operating state informations. The system operates unattended at night and on holidays.

**SYSTEM OPERATION**

Based on the startup, operation, and shutdown requirements and consideration of the need to protect the generator; the following operating states are utilized.

1) PREOP (Preoperation); The controller confirms the system status for initial startup.
2) PURGE; The generator is purged with hydrogen mixed nitrogen gas to remove oxygen from anode side.
3) HEAT; The generator is heated to 600 °C in its center temperature by the electric air preheater and by burning hydrogen in the combustion zone.
4) LOADH (Load Hydrogen); The SOFC module initially generates current in this state. The function of this state is to establish recirculation of the water vapor needed for reforming natural gas by drawing current from the generator.
5) LOADP (Load Primary); The hydrogen flow is slowly decreased as natural gas flow is increased to complete the transition from operation on hydrogen to operation on natural gas.
6) RUN; This state permits automatic control of the generator for normal operation.
7) STOP; The generator cools down actively or passively (in the event of system trouble), maintaining system integrity and healthy conditions for cells.

One module was started up on the 25th of February 1992 and the other module was started up on the 27th. Operation went smoothly with stable operation at a high fuel utilization of 85%. The typical parameter profile of the generator during startup is...
shown in Figure 5.

ESTIMATED SYSTEM PERFORMANCE

In Figure 6, dc power parameters are presented as functions of module current. Net system power is evaluated by subtracting the parasitics and the electric air preheat power from the terminal dc power. SOFC system and module efficiency predictions are presented in Figure 7. The peak system efficiency appears at a generator current of 152 amperes where no electric air preheater power is needed, and with net system output of approximately 25 kW ac equivalent and an efficiency of 33 % (net dc eff. /HHV).

Table 1. SYSTEM SPECIFICATIONS

| Item                        | Specification             |
|-----------------------------|---------------------------|
| Gross D.C. output           | 36kW (44kW max)          |
| Net A.C. output (assumed)   | 25kW                      |
| Fuel                        | City gas                 |
| Reforming process           | Internal reforming       |
| Operating temperature       | 1000°C                   |
| Operating pressure          | Atmospheric pressure     |
| Cooling system              | Process air cooling      |
| Exhaust heat using system   | Inlet air heating         |
| Load condition              | D.C. dissipator          |

| Item                        | Specification             |
|-----------------------------|---------------------------|
| Operating mode              | Automatic operation at a preset load |
| Module size                 | (D) 1.8 m (W) 1.3 m (H) 2.2 m |
| Module weight               | 3720 kg                   |
| Number of modules           | 2 modules                 |
| Number of cells per module  | 576 cells                 |
| Open circuit module voltage | 192 V                     |
| Active cell length          | 50 cm                     |
| Cell output                 | 35 W (42 W max)           |
| Number of prereformers per module | 4 prereformers            |
