SOLID OXIDE FUEL CELL SYSTEMS FOR STATIONARY POWER GENERATION APPLICATIONS

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ABSTRACT

This paper discusses the progress and status of two solid oxide fuel cell (SOFC) systems being developed for stationary power generation applications: 3-10 kW simple-cycle, ambient-pressure SOFC systems and MW-class pressurized SOFC/gas turbine (GT) hybrid systems. The SOFC for both the systems is based on a planar design and operates at about 800°C. The fuel cell can also operate efficiently with fuels containing light hydrocarbons. To date, a prototype for the 3-10 kW system has been designed and is in construction. Several configurations have been developed for power plants based on MW-class SOFC/GT hybrid systems and the feasibility of pressurized operation for laboratory-scale planar SOFCs has been demonstrated.

INTRODUCTION

Solid oxide fuel cell (SOFC) technology has been developed for a variety of power generation applications (1,2). SOFC power systems that have been considered range from portable devices (e.g., 500-W battery chargers) and small generators (e.g., 5-kW residential power or automobile auxiliary power units) to distributed generation power plants (e.g., 100-500 kW power plants) (3). SOFCs can also be integrated with a gas turbine to form large (several hundred kW to multi-MW) pressurized hybrid systems. The SOFC is the only type of fuel cell that has the potential for such a wide range of applications. This paper discusses the progress and status of two SOFC systems being developed for stationary power generation: 3-10 kW simple-cycle, ambient-pressure SOFC systems and MW-class pressurized SOFC/gas turbine (GT) hybrid systems.

AMBIENT-PRESSURE 3-10 kW SOFC SYSTEM

The ambient-pressure 3-10 kW system being developed at GE is a stationary power generator with a SOFC stack as the power generating unit. The key features of the system include a fuel-flexible pre-reformer, a high-performance planar SOFC that is capable of internal reforming of light hydrocarbons, integrated thermal management, and suitable control and efficient power management subsystems (4). A prototype for this system has been designed (schematically shown in Figure 1). Layout concepts for the prototype system have been developed using actual component design drawings for those items that had been identified to date and derived conceptual design models for other components. One of such layout is shown in Figure 2.
The status of certain key components/subsystems developed and evaluated for the prototype is summarized below:

**SOFC Stack**

Cells of the baseline design and configuration have been produced for the prototype, and performance (0.4 W/cm², 0.7 V, 88% fuel utilization) exceeding the target (0.3 W/cm², 0.7 V, 88% fuel utilization) has been demonstrated. Extraordinarily high fuel utilizations (Uf) up to 95% in 64% H₂-36% N₂ at 800°C have also been demonstrated. Multi-cell stacks have been operated with fuels containing up to 30% methane. Alloys with...
improved oxidation resistance for interconnects have been developed. SOFC stacks of
the baseline design (up to 40-cell to date) have been built and operated. Figure 3 shows
the performance of a 21-cell stack tested with 64% H₂-36% N₂ fuel at 800°C.

![Figure 3. Performance of 21-Cell Stack.](image-url)

**Pre-Reformer**

Figure 4 is a photograph of an autothermal (ATR) pre-reformer designed and built for the
prototype. The fuel processor has shown the ability to meet the system requirements
(steam-to-carbon ratio, oxygen-to-carbon ratio, inlet temperature, methane slip, pressure
drop). The integration of the pre-reformer with SOFC stacks has also been demonstrated.

![Figure 4. ATR Pre-Reformer.](image-url)

**Controls**

A multi-level design for the control subsystem, including top-level supervisory
algorithms and active controls, has been developed and implemented in software for the
prototype system.
Power Electronics

A power electronics unit has been fabricated and tested. The unit has achieved efficiency >94% over a wide range of power (3 to 6 kW).

PRESSURIZED SOFC/GT SYSTEM

The SOFC/GT hybrid concept integrates a planar SOFC with a GT in a “directly fired” configuration, i.e., the system uses a pressurized SOFC to provide input to the turbine, thus acting as a combustor. In general, the GT provides 20 to 35% power of the system as shown below:

| System Size | Gas Turbine Size |
|-------------|------------------|
| 1 MW        | 200 to 350 kW    |
| 10 MW       | 2 to 3.5 MW      |
| 200 MW      | 40 to 75 MW      |

For smaller size systems (e.g., 1 to 10 MW), the pressure ratio (P/P) is 3:1 to 6:1 whereas for larger systems (e.g., 200 MW), the P/P is 8:1 to 12:1. Figure 5 shows a conceptual MW-class SOFC/GT power plant.

Figure 5. Conceptual MW-Class SOFC/GT Power Plant.

Analysis of the SOFC/GT concept has indicated that hybrid systems are capable of producing electricity at >65% efficiency. Various system design options have been considered along with assessment of their performance and operating characteristics. In addition, integration of SOFC/GT systems with a gasification combined cycle (IGCC) to form multi-MW power plants (referred to as integrated gasification fuel cell systems or IGFCs) has been evaluated. Figure 6 is a block diagram of an IGFC with carbon dioxide separation. The integration of the SOFC/GT hybrid in a 300 MW IGCC system has the potential to increase the overall system efficiency to about 53-54% (about 10 to 15 points higher than IGCCs). Incorporation of CO₂ separation reduces the overall efficiency by about 2-3 points (Figure 7).
Several important technological milestones have been achieved:

- Pressurized operation (up to 4 atm) of planar SOFC stacks has been achieved. This is the first time such a planar SOFC has been operated under pressure.
- Fuel utilization up to 80% has been demonstrated. This is also the first time such high utilization has been reported for planar SOFCs under pressures.
- Single cells up to 12.75 inch diameter have been produced to demonstrate fabrication of large-area SOFCs suitable for hybrid systems (Figure 8).
• Performance degradation of the SOFC under 4 atm has been found to be higher than ambient pressure. Further work is required to quantify the degradation rate and the mechanisms responsible for increased degradation.

• Pressurized operation of SOFC on simulated steam reformate has indicated that stable performance is obtained at steam-to-carbon ratio of 1.0 but carbon formation occurs at ratio of 0.5 at 4 atm and 800°C.

Figure 8. Photograph of a Large-Area Cell.

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Electrochemical Society Proceedings Volume 2005-07 81