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Authors:
R.A. Brown

Contractor:
Westinghouse Science & Technology Center
1310 Beulah Road
Pittsburgh, PA 15235-5098

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SOFC COMBINED CYCLE SYSTEMS FOR DISTRIBUTED GENERATION

RAYMOND A. GEORGE
Manager
SOFC Power Generation
Westinghouse Science & Technology Center
Pittsburgh, Pennsylvania

Westinghouse Electric Corporation has been making great strides in advancing tubular Solid Oxide Fuel Cell (SOFC) technology towards commercialization by the year 2001. Over the last 10 years of tubular SOFC development, cell power output was increased by over a factor of 10 as shown in Figure 1, the size of SOFC power systems was increased from 3 kWe to 150 kWe, two cells operated for 69,000 hours (7.9 years) setting a fuel cell world record, a 25 kWe power system operated for 13,000 hours (1.5 years) with only 1% voltage loss, and cells were electrically tested under pressurized conditions up to 15 atmospheres, corroborating the analytical model predictions.

The final phase of the tubular SOFC development program will focus on the development and demonstration of pressurized solid oxide fuel cell (PSOFC)/gas turbine (GT) combined cycle power systems for distributed power applications. The commercial PSOFC/GT product line will cover the power range 200 kWe to 50 MWe, and the electrical efficiency for these systems will range from 60% to 75% (net AC/LHV CH4), the highest of any known fossil fueled power generation technology. Figure 2 illustrates the features of this combined cycle. The compressor portion of the gas turbine delivers pressurized and recuperated air to the SOFC module(s). Except for startup, the natural gas fuel is fed only to the SOFC module(s). The fuel and oxygen in the air electrochemically react within the module(s) to produce DC electrical power and hot exhaust gas. The hot exhaust gas is directed to the expander portion of the gas turbine driving the air compressor and an electric generator. The SOFC exhaust gas temperature is typically 1550°F and the operating pressure, at least for the early commercial units, will be in the range 3 to 7 atm gauge, which are very compatible with existing industrial gas turbine technology.

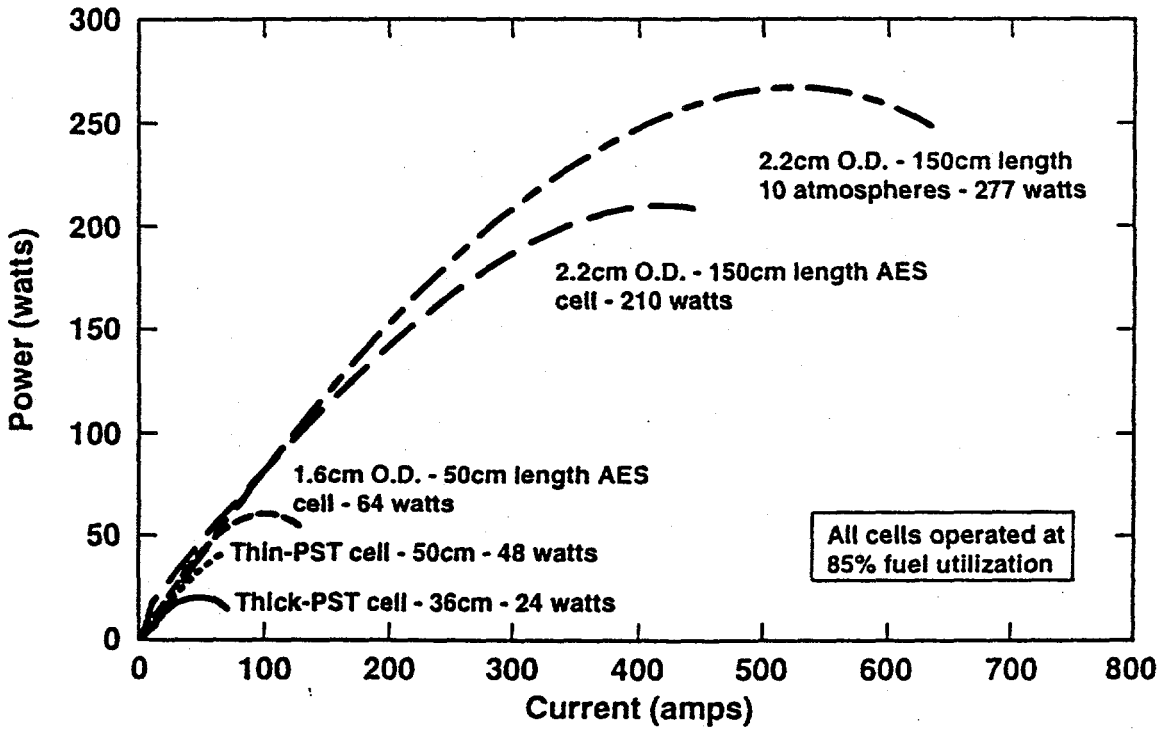

Figure 1. Advancements in Tubular SOFC Power Output.

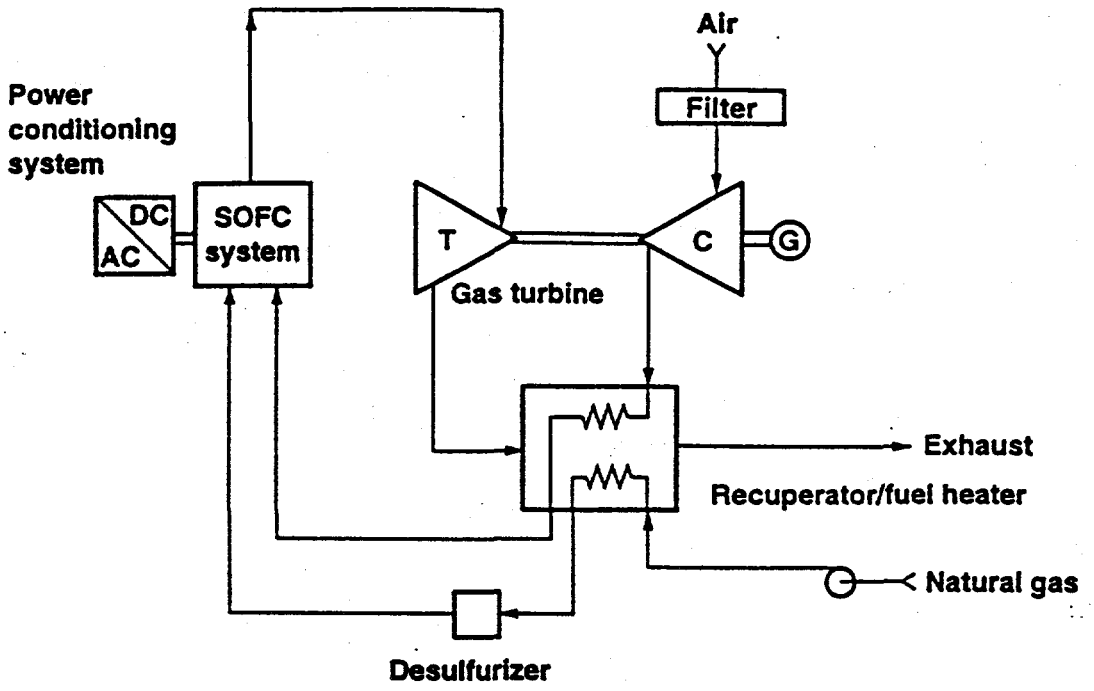

Figure 2. Simplified PSOFC/GT Schematic.

The first demonstration of a pressurized solid oxide fuel cell/gas turbine combined cycle will be a proof-of-concept 250 kWe PSOFC/MTG power system consisting of a single 200 kWe PSOFC module and a 50 kWe microturbine generator (MTG). This system, which is being designed and built with funds from the U.S. Department of Energy (DOE), a U.S. utility, and Westinghouse Electric Corporation, is scheduled for initial startup in June, 1998 at a U.S. utility selected site. Table 1 presents performance estimates for a 250 kWe PSOFC/MTG power system. Note that an electrical efficiency of 62% is achievable at a power output rating of only 250 kWe. This demonstration will provide valuable "lessons learned" in the design, build and operation of such systems applicable to the subsequent "MWe-Class" combined cycle demonstration described below.

The second demonstration of this combined cycle will be 1.3 MWe fully packaged, commercial prototype PSOFC/GT power system consisting of two 500 kWe PSOFC modules and a 300 kWe gas turbine. The program plan and funding consortium, tentatively

Table 1. 250 kWe PSOFC/MTG System Performance Estimates

Parameter	Design Point
Pressure ratio	3.5
Compressor air flow rate, lb/hr	3720
Turbine inlet temperature, °F	1524
SOFC current density, mA/cm^2	327
Cell current, amps	281
Cell voltage, volts	0.695
SOFC fuel utilization, %	80
SOFC stoichs	3.7
SOFC fuel flow rate, lb/hr	70.1
MTG combustor fuel flow rate, lb/hr	0
SOFC bypass air flow	0
Electric heater power	0
SOFC ac power, kWe	214.9
MTG ac power, kWe	46.6
Plant ac power output, kWe	261.5
Plant ac efficiency (ac/LHV), %	62.3

consisting of one or more Electric Utilities, DOE, Westinghouse, an industrial gas turbine manufacturer, and the Environmental Protection Agency (EPA), are currently being organized with the objective of initiating testing at EPA's new laboratory located at Fort Meade, Maryland by first quarter 2000. This system will produce electrical power with a 63% electrical efficiency, and will be very representative of early commercial units to be offered in the market place starting in the year 2001.

The final demonstration phase is less well developed but conceptually will consist of upgrading the 63% efficient, 1.3 MWe system to a 70% efficient, 2.5 MWe system and initiating testing in late 2000/early 2001. This will be accomplished by adding two more 500 kWe PSOFC modules, and changing the gas turbine from a single shaft 300 kWe engine to a dual shaft (gas generator and power turbine) 500 kWe system. As shown in Figure 3 two of the four 500 kWe PSOFC modules will provide the turbine inlet gas to the gas generator at 9 atm gauge. The gas generator exhaust will be at 3 atm gauge and be reheated by the other two 500 kWe PSOFC modules prior to entering the power turbine. This dual shaft concept in combination with the SOFC reheat feature allows the attainment of previously unimaginable electrical efficiencies exceeding 70%.

Our commercialization plan calls for delivering the first commercial PSOFC/GT power system in late 2001. These early systems will have ratings in the 1-3 MWe range, electrical efficiencies in the 60-65% range, and NOx, SOx emissions below the limits of detectability. In addition, two detailed cost studies on the Westinghouse PSOFC/GT system performed by consultants to DOE have concluded that a total installed cost of $1000/kWe is achievable under large production volume assumptions. Based upon the system performance attributes and cost studies, Westinghouse believes that PSOFC/GT power systems will play an important role in the power generation mix of the 21st century.

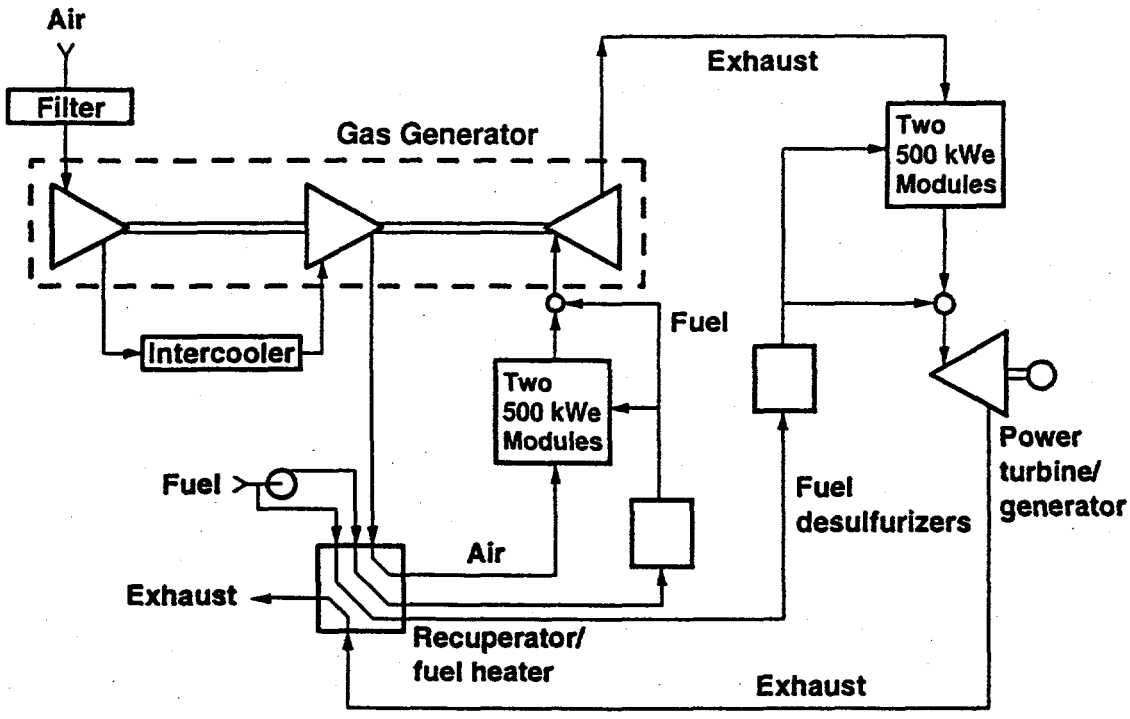

Figure 3. 2.5 MWe PSOFC/GT System Schematic.