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High Temperature Tubular Solid Oxide Fuel Cell Development

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CONTRACT INFORMATION

Cooperative Agreement	DE-FC21-91MC28055
Contractor	Westinghouse Electric Corporation 1310 Beulah Road Pittsburgh, Pennsylvania 15235-5098 (412) 256-2125
Contractor Program Manager	Mr. Emerson R. Ray
METC Project Manager	Ms. Diane T. Hooie
Period of Performance	April 1, 1991 to November 30, 1995
Schedule and Milestones	

FY1992 Program Schedule

	O	N	D	J	F	M	A	M	J	J	A	S
Market/User Assessment Studies												
Reference Design												
Base Cell Technology												
100 Cm Porous Support Tube (PST) Cell Dev.												
100 Cm Air Electrode Supported (AES) Cell Dev.												
Alternate Process Development												
100 to 200 Centimeter Cell Development												
Process Scale-up/Optimization/ Cost Reduction												
Facility Construction/Field Test Gen. Support												
Long Cell Test Station Design and Construction												
Cell and Bundle Testing												
Generator Development												
Joint Field Unit Module Fabrication												
Joint Field Unit Gen./System Fab./Test												

OBJECTIVES

The ultimate objective of this project is to develop tubular solid oxide fuel cell (SOFC) technology to the point of acceptable risk for private sector commercialization. This objective involves the development of commercial market reference designs which, in turn, will define SOFC cost and performance criteria.

The Cooperative Agreement is intended to advance the SOFC technology to the next phase of the total ultimate objective. It is intended that cell technology, which meets cost and performance criteria, will be developed and demonstrated.

This paper presents an overview of the Westinghouse tubular Solid Oxide Fuel Cell (SOFC) Technology, current program status and realized progress in the field test programs. Activities which have followed the successful completion of the Multi-Kilowatt Generator (MKG) testing program are discussed herein.

BACKGROUND INFORMATION

Advancements under this continuing program have resulted in the development of cells with greatly improved performance, reduced rate of degradation and increased life as well as the design, construction, and test of cell bundles and generator modules. Multiple single cell tests have now successfully exceeded 30,000 hours of power operation at temperature, and multiple generator tests have been successfully performed.

In 1980, a contract was initiated between Westinghouse and the U.S. Department of Energy and administered by the Morgantown Energy Technology Center. This cost share program centered on continuing to develop, improve, and scale-up the tubular SOFC technology for use with coal derived fuels.

In the latter part of 1986, Westinghouse signed a contract with the Gas Research Institute to develop SOFC technology specifically for use with natural gas and directed toward applications in the commercial and industrial cogeneration market (20 kWe to 2 MWe). The primary objective of the effort was the development of an SOFC generator that can consume natural gas directly - without the need for a separate fuel processing system. A 3 kW generator was designed, fabricated and successfully tested at Westinghouse as part of the GRI program.

In mid 1987, the GRI program was expanded to include the study of applications and markets, and the development of conceptual designs and cost estimates for on-site cogeneration applications in the power range from 20 kWe to several megawatts. This effort was sponsored by a consortium of gas utilities in Japan (Tokyo Gas, Osaka Gas, Toho Gas) in cooperation with the Japanese New Energy and Industrial Development Organization (NEDO).

In 1991, a Cooperative Agreement was initiated between Westinghouse and DOE-

Morgantown Energy Technology Center, covering a project period through November 1995. This ongoing program is focused on the continued development, improvement, and scale-up of the tubular SOFC for use with natural gas and coal-derived fuel gas.

Tubular SOFC technology is in the preliminary design stage of development and Westinghouse plans for field testing of multi-hundred kilowatt and multi-megawatt rated generators during the mid to latter-1990's.

PROJECT DESCRIPTION

Successful commercialization of the SOFC technology during the 1990's depends on the ability to produce cost competitive systems that can operate for five to ten years before replacement of the SOFC module(s). A thorough understanding of the phenomena that limit cell and generator lifetime is required so that new processes and/or materials can be developed. Furthermore, a detailed understanding of the manufacturing costs of cells and generators is also required in order to develop more cost effective processes and procedures.

The Westinghouse goal is to develop a cell that can operate for 50,000 to 100,000 hours with a voltage degradation rate of less than 1% per 1000 hours. To date, Westinghouse has produced and operated for extended periods more than one thousand cells and has systematically improved cell performance, life, and voltage stability. A historical record of the progress made by Westinghouse relative to SOFC voltage degradation is presented in Figure 1. Ongoing cell tests have surpassed 30,000 hours of operation with degradation rates in the range of 0.5 to 1.5% per 1000 hours.

To enhance economic viability, Westinghouse is working to reduce the manufacturing costs of the cells and generators and to increase the power output per cell. Engineering studies indicate acceptability of the present cell diameter (approximately 1.5 cm), however, longer cells and increased power output per unit cell length contribute to improved power plant economics. Over the past few years Westinghouse has successfully increased the active length of the SOFC from 30 cm (in pre-1986 cells) to 100 cm (currently in production)

with the results being a corresponding increase in power output per cell.

Figure 1. Improved Cell Performance and Life Verified by Ongoing Testing

In parallel with increasing the cell length, Westinghouse also progressively reduced the thickness of the porous support tube (PST). Early technology SOFCs had a 2 mm thick PST (defined as a thick-wall PST) that provided the support structure for the SOFC. Although sufficiently porous to allow air flow to the air electrode, there was an inherent impedance to air flow towards the air electrode. Efforts were successful in first reducing the PST wall thickness to 1.2 mm (the thin-wall PST) and ultimately in eliminating the PST altogether. As the PST wall thickness was reduced and the PST eventually eliminated from the cell, the air electrode thickness was increased. The present technology SOFCs have an air electrode thickness that is sufficient to support the cell. The air electrode supported (AES) cell does not require the PST, thus eliminating the air flow impedance toward the air electrode and further improving cell efficiency and power production. Figure 2 depicts the evolution of the design of the Westinghouse SOFC. The combined effect of increasing the cell length from 30 cm to 100 cm and eliminating the PST, resulting in a six-fold increase in cell power output, is shown in Figure 3. Now in the initial stage of production are AES cells with a 100 cm active cell length. Application studies reveal that the 100 cm AES cells can satisfy a segment of the commercial market

requirements in the 1990's and beyond, however, longer cells will further improve the economics, particularly for large central station electric utility power plants. The present development program is addressing the manufacture of longer cells.

Figure 2. Evolution of Tubular Solid Oxide Fuel Cell Design

Additional cost and performance benefits can be realized by the direct use of natural gas by the SOFC. This can be achieved by reforming the natural gas into hydrogen and carbon monoxide within the SOFC generator. Work sponsored by DOE, Westinghouse, and GRI has led to the concept of internal reforming. Through a unique fuel delivery system and exhaust gas recirculation, both developed by Westinghouse, the need for an external fuel reformer and an external steam source are eliminated. This reduces plant complexity and permits the energy that would normally be required to generate the reforming steam to be utilized in a more efficient manner. This key development goal was achieved in 1988/1989 with the successful demonstration of a 3 kW SOFC generator that operated directly on pipeline natural gas (PNG). The 3 kW SOFC generator was equipped with an internal reformer that reformed 75% of the incoming natural gas. The remaining 25% was reformed directly on the exterior surface of the SOFCs (the fuel electrode). The energy and steam required for reforming the natural gas was supplied by recirculating a portion of the spent fuel and exhaust gas. The 3 kW SOFC generator operated for more than 5000 hours on pipeline natural gas. Additional design efforts are

underway that will eliminate the internal reformer and will reform all of the fuel on fuel distribution/electrode surfaces within the SOFC generator.

technology from a laboratory environment to a manufacturing environment and enables the development of processes and quality control programs that are required for successful commercialization of the SOFC technology.

Figure 3. Increased Power Density Realized Through SOFC Development

A major step in the technology development program was the Westinghouse investment of capital funds to construct the Pre-Pilot Manufacturing Facility (PPMF), Figure 4.

Figure 4. Photograph of the Westinghouse Pre-Pilot Manufacturing Facility

The 28,000 ft² PPMF is dedicated to SOFC manufacturing development. This facility provides the opportunity to move the SOFC

The PPMF has manufactured in excess of three thousand 50 cm thin-wall PST SOFCs in support of both the technology development program and the field test program (described in the following section of this report). It is presently in the process of manufacturing the latest generation of SOFCs, the 100 cm AES cell, and it is anticipated that even longer cells will be manufactured at the PPMF.

A major milestone reached in 1990/1991 was the operation of the DOE-sponsored multi-kilowatt generator (MKG), shown in Figure 5.

Figure 5. Photograph Showing the 20kWe SOFC, MKG

The MKG, rated at 20 kW, consisted of 576 thin-wall PST cells with an active length of 50 cm. This unit was tested for more than 3000 hours, 1760 on pipeline natural gas, 750 hours on naphtha, and the balance on hydrogen fuel. This unit is a significant event in that it represents nearly an order of magnitude scale-up in power rating relative to previous SOFC generators operated by Westinghouse.

The next larger SOFC generator, nominally rated at 100 kW is in the conceptual design stage. This unit will incorporate state-of-the-art technology such as 100 cm AES cells and internal reforming of natural gas.

RESULTS

Important to the development and commercialization of any new technology is a field test program. This is a mutually beneficial program for both the developer and the prospective user. The developer is able to acquire valuable field operating experience that is not available in a laboratory while the user has the opportunity to become familiar with the new technology and gains a working knowledge of it through hands-on experience. Westinghouse, recognizing these benefits, initiated such a program in 1986 by supplying a 400 W SOFC generator to the Tennessee Valley Authority (TVA). This generator operated for approximately 1,760 hours and was constructed of twenty-four 30 cm thick-wall PST cells.

In 1987, three, 3 kW SOFC generators were installed and operated at the facilities of the Tokyo Gas Company and the Osaka Gas Company. At Osaka Gas, two generators were used. The first, a training generator, operated for 2900 hours before it was replaced on a preplanned schedule with the second generator. The second generator operated for 3,600 hours. The Tokyo Gas generator was operated for 4,900 hours. These generators had a 98% availability and measured NO_x levels of less than 1.3 ppm. The 3 kW SOFC generators were constructed of 144 36 cm thick-wall PST cells. The 3 kW generators, as was the TVA generator, were fueled with hydrogen and carbon monoxide.

The next major milestone in the field unit program was reached in early 1992 with the delivery to The UTILITIES, a consortium of The

Kansai Electric Power Company, the Tokyo Gas Company, and the Osaka Gas Company, of a natural gas fueled all electric SOFC system. This system is rated at a nominal 25 kW dc with a peak capacity of 40 kW dc. The NO_x was measured at <0.3 ppm (corrected to 15% oxygen). The system consists of 1152 cells (thin-wall PST) of 50 cm active length, manufactured at the PPMF. The cells are contained in two independently controlled and operated generators. 2,300 hours of stable operation has been obtained on the first unit. The second unit is shutdown for repairs. Testing was initiated in February 1992. A photograph of the 25 kW SOFC system is presented in Figure 6.

Figure 6. 25 kW Tubular SOFC Field Unit Generator

A second 25 kW SOFC system is presently being fabricated and will produce ac power and intermediate pressure steam. This cogeneration system will be delivered in 1992 to the Joint Gas Utilities (JGU), a cooperative effort between Tokyo Gas Company and Osaka Gas Company.

These Field Units represent practical incorporation of the lessons learned in the designing, manufacturing and operating of the MKG generator (20kW) at Westinghouse in Pittsburgh and demonstrate significant technology scale-up.

SUMMARY

A summary of significant developments and accomplishments which have recently occurred throughout the tubular SOFC program include:

- Demonstration that thousands of tubular solid oxide fuel cells can be fabricated with consistent and reproducible performance.
- Continuous operation of a 3 kWe tubular SOFC system for over six months at a customer's test site.
- Demonstration of stable performance and lifetime in excess of 5,300 hours for a 3 kWe generator module, operating directly on non-humidified desulfurized natural gas.
- Demonstration of stable performance and life times in excess of 30,000 hours in multiple single cell tests.
- Design, construction and operation of a dedicated cell, module and generator Pre-Pilot Manufacturing Facility (PPMF).
- Successful 6,840 hour bundle tests of 50 cm. cells produced at the PPMF.
- Significant improvements in cell performance and life and marked reduction in cell degradation.
- Design, construction and successful operation of a 20 kWe tubular solid oxide fuel cell generator module.
- Design, construction, shipment and installation of two 25 kWe (40 kWe peak power) field units.

FUTURE WORK

The existing Cooperative Agreement between Westinghouse and the Department of Energy was initiated in April, 1991 and will continue through November 1995. This five year program includes considerable financial contributions from Westinghouse, from domestic and foreign utilities, and from other agencies, in

addition to the U.S. Department of Energy. Under this program Westinghouse will continue development of the tubular solid oxide fuel cell technology and generator systems and plans for field testing of multi-hundred kilowatt and multi-megawatt rated generators during the mid to latter-1990's. The ultimate objective of this program is to develop tubular SOFC technology to the point of acceptable risk for private sector commercialization.

Development of the tubular solid oxide fuel cell technology is being supported by the Westinghouse Electric Corporation, the United States Department of Energy (DOE-METC), and various utility and industry sources. The Cooperative Agreement between Westinghouse and DOE is administered by the Morgantown Energy Technology Center (METC). Funding for the evaluation of Westinghouse pressurized SOFC technology for utility applications in Japan is being supplied by a Japanese consortium composed of the New Energy and Industrial Technology Development Organization (NEDO), The Hokkaido Electric Power Company, The Tokyo Electric Power Company, The Chubu Electric Power Company, The Chugoku Electric Power Company, The Kyushu Electric Power Company and The Electric Power Development Company (EPDC).

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