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Solid polymer fuel cells for transport and stationary applications

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Abstract

Progress is reported toward the commercialization of solid polymer fuel cell (SPFC) (also known as the proton-exchange membrane or PEM fuel cell) technology. A full size transit bus powered entirely by an SPFC, sufficiently compact to fit within the standard bus engine compartment, is described. The first order for a test fleet of these buses is also reported. Progress in the development of fuel cell stacks for stationary and motive applications is described. A high power density SPFC stack producing over 1000 W/l is reported.

Keywords: Solid polymer fuel cells; Transport applications; Stationary applications

1. Introduction

Substantial progress has been made toward the commercialization of solid polymer fuel cells (SPFC) (also known as proton-exchange membrane or PEM fuel cells) [1]. By virtue of its intrinsic simplicity and high power density, the SPFC/PEM fuel cell has the distinct advantage, over other fuel cell technologies, of being appropriate for both stationary and motive applications. Ballard Power Systems is pursuing product development and commercialization of the PEM fuel cell in both market areas. As a part of its commercialization strategy, Ballard has embarked on a series of programs to demonstrate the status and value of the PEM fuel cell in practical use.

2. Demonstration/commercialization programs

2.1. Stationary applications

Ballard is in the midst of a four-phase program to commercialize stationary PEM fuel cell power plants, operating on natural gas and producing grid quality a.c. power, by the year 2000. The first phase of that program involved the development and demonstration of an integrated subscale unit, incorporating all the components necessary for a commercial unit. In particular, the subscale unit included a natural gas reformer, shift converter, and selective oxidizer to provide a hydrogen-rich gas stream appropriate for the fuel cell. The unit also included a PEM fuel cell system designed to be tolerant of the impurities in the fuel stream, all ancillary and control systems, and a d.c. to a.c. converter.

This subscale test unit, shown in Fig. 1, was completed on schedule in 1993 and has been undergoing testing since that time. A second similar unit has just been completed and will join the first unit in a component test program. In parallel with that test program, Ballard has begun phase 2, in which it is developing the engineering prototype of the ultimate 250 kW commercial unit.

The reformer and air supply subsystems of the 250 kW prototype are now being tested. The 280 kW fuel cell stack for this prototype power plant will be completed early next year. These development activities are on schedule for the demonstration of pre-commercial units in a utility environment in the 1997–1999 time frame, with commercial units being available soon thereafter.

2.2. Transportation applications

Ballard is developing fuel cell stacks and power plants for a variety of transportation applications ranging from buses and automobiles to submarines and surface ships. Ballard's fuel cell powered bus program is a four-phase program, which began in 1990 with a feasibility demonstration first phase, and will culminate with fuel cell-powered, zero-emission buses being commercially available in 1998.

The first phase of this program demonstrated the feasibility of powering a small commercial bus with a PEM fuel cell power plant. That bus was completed in 1992. The details of its construction and operation have been reported elsewhere [2].

The phase 1 bus successfully demonstrated that a PEM fuel cell power plant was capable of providing the entire power requirement for such a vehicle. This fuel cell-powered bus

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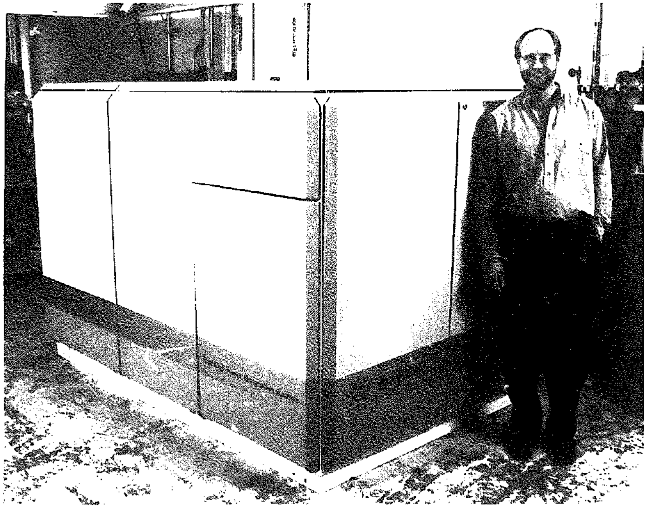

Fig. 1. Sub-scale test unit for natural gas-fueled PEM fuel cell power plant.

exhibits the same performance as the diesel version of the bus, yet, as it is fueled by gaseous hydrogen, it qualifies as a zero-emission vehicle. While the first bus has been very successful as a feasibility demonstration and engineering test bed, it is not a commercial vehicle. The engine, based upon Ballard's first generation MK 5 fuel cell stacks, occupies about 25% of the volume of the bus.

The objective of phase 2 of the bus commercialization program was the development of an engineering prototype for a commercial bus engine and the demonstration of a full size transit bus powered by such an engine. To be commercially viable, the fuel cell engine must provide the same performance as the diesel engine it is replacing, without encroaching into passenger space. That objective has been achieved and is now being demonstrated in a full sized, 40 ft commercial transit bus. The engine, consisting of twenty second generation PEM fuel cell stacks, each delivering a net 10 kW under the engine operating conditions, produces a total of 200 kW or about 275 hp — the same power as the diesel engine typically installed in this bus. This fuel cell power plant provides the entire motive power for the bus, as well as providing power for lighting and air conditioning. The compact engine is shown in Fig. 2.

The completed bus is shown in Fig. 3. With the PEM fuel cell power plant, this bus produces the same top speed and hill climbing capability as the diesel powered bus and delivers much better acceleration. Gaseous hydrogen fuel is stored in cylinders arranged on the roof of the bus, in the same configuration as the natural gas diesel version of the bus. With fuel stored as a pressure of 3000 psi, the bus has a range of 400 km (250 miles).

The next phase in the bus commercialization program is the production of two or three small fleets for testing by transit companies in routine operation. The first such fleet has been ordered by the Chicago Transit Authority. After this testing program is complete, commercial buses will be available in 1998. The commercial buses will be powered by engines based upon a third generation fuel cell stack, to be described below. With the possible incorporation of an energy recovery system for regenerative breaking, the range of the commercial bus can be about 560 km (350 miles).

Several automakers are developing compact PEM fuel cell engines for automotive applications. Most notable to date is the activity of Daimler–Benz, which has demonstrated a small van powered entirely by Ballard's first generation MK 5 fuel cell stacks.

3. Stack development progress

3.1. Stationary power plants

The phase 1 subscale natural gas power plant, shown in Fig. 1, contains a fuel cell array, based upon MK 5 technology. The power unit consists of four 106 cell stacks oriented vertically. The four stacks are connected in series to provide a power plant voltage of 320 V d.c. at the rated system operating power of 22 kW. At peak power, the fuel cell unit, shown in Fig. 4, will produce 40 kW.

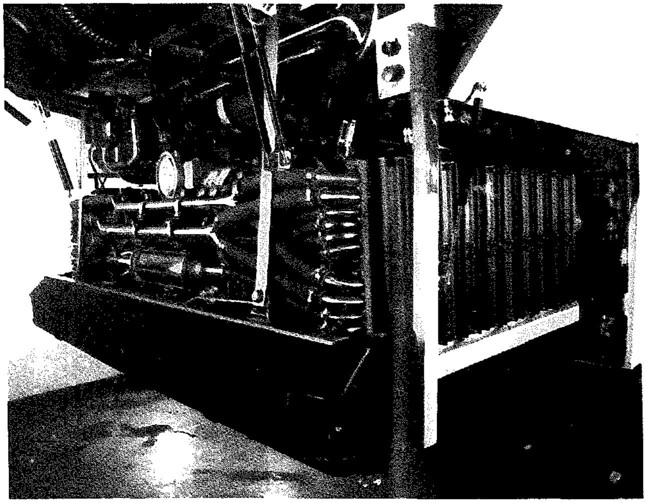

Fig. 2. Compact 200 kW (275 hp) PEM fuel cell engine which powers Ballard's full size prototype transit bus.

Fig. 3. Prototype of the commercial zero-emission transit bus, powered entirely by a 200 kW PEM fuel cell power plant.

A second generation of stationary stacks, which incorporate plastic manifolds, and other improvements related to reliability and cost, has been developed and is being tested. This design has been developed into a 1.4 sq ft active area cell for the 280 kW gross power stack to be incorporated into the commercial natural gas power plant. This large area design has been tested in single cell and small stack versions and yields baseline performance.

3.2. *Transportation power plants*

Fig. 5 shows the evolution of Ballard's PEM fuel cell stacks for transportation applications. The stack on the left in Fig. 5 is the MK 5 stack, which was introduced in 1990 and powered the first bus and the Daimler–Benz van. The performance of that stack has been reported elsewhere [1], but operating under Ballard's standard operating conditions of

Fig. 4. PEM fuel cell four stack array delivers 22 kW at 320 V d.c. in the sub-scale natural gas test unit or 40 kW at peak power.

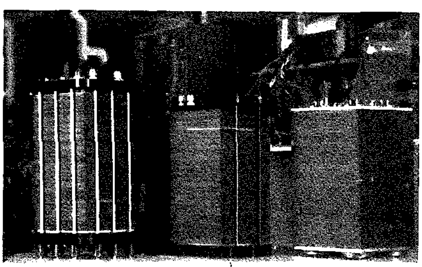

Fig. 5. The development of PEM fuel cell stacks for transportation applications. Left, MK 5 stack produces 5 kW; center, MK 513 stack produces 13 kW; right, MK 7 stack produces over 32 kW.

30 psig (3 atm) for both the hydrogen and the air, and a stoichiometry of 2.0 for air and 1.5 for hydrogen, this stack produces 5 kW at an average cell voltage of 0.57 V. This translates to a power density of about 150 W/l or W/kg. It should be noted that this stack includes an integral membrane humidifier, so that the power density of the active fuel cell stack is somewhat higher.

The stack in the center of Fig. 5, which powers Ballard's second bus, represents an improvement of the MK 5 technology. The humidification section has been moved to a position upstream of the active fuel cell section. This change in orientation allows the elimination of the manifolding which, in the MK 5 stack, passes dry air, dry hydrogen, and cooling/humidifying water through the active section of the stack to the humidifier. The elimination of those three manifolds allows a greater proportion of the area of the flow field plates to be allocated to the active electrochemical area, thus increasing the current available from the same total flow field plate area. This improved stack, designated MK 513, produces 13 kW under Ballard's standard operating conditions at an average cell voltage of 0.58 V. This represents a power density of about 300 W/l or W/kg. Again, the power density of the active portion of the fuel cell stack is somewhat greater.

The stack on the right of Fig. 5 was developed jointly by Ballard and Daimler–Benz. This stack, which occupies a volume of 31.9 l, produces a continuous power of 32.3 kW at an average cell voltage of 0.68 V. This performance was obtained at a somewhat lower operating pressure than the standard Ballard MK 5 conditions and at stoichiometries specified by Daimler–Benz for their proposed system. Under these higher efficiency operating conditions, the stack still delivers over 1000 W/l and over 700 W/kg.

This stack meets or exceeds the various power density targets identified by automakers, by the US Department of Energy, and by the Partnership for a New Generation Vehicle (PNGV). The significance of these data is that the development and commercialization issues for this technology have now shifted from attaining the necessary power density to retaining that power density in fuel cell stacks which can be manufactured in volume at costs competitive with the internal combustion engine.

4. Cost reduction activities

Many workers have reported substantial progress in reducing the amount of platinum catalyst required for acceptable fuel cell performance (see Ref. [1] and Refs. cited therein). There is little doubt that PEM fuel cells can be made with total catalyst loadings of less than 1 mg/cm^2. Ballard is pursuing a program with Johnson–Matthey to develop mass production techniques for applying low loading catalysts, while maintaining performance.

Ballard has recently announced [3] the development of a new, low cost membrane electrolyte with performance equivalent to or better than available commercial electrolytes. As this material, based upon a trifluorostyrene polymer, is less fluorinated than the commercial membrane electrolytes, it appears that this membrane will be substantially less costly. To date, cells containing this membrane electrolyte have exhibited over 4000 h of operation with essentially no degradation in fuel cell performance.

Several organizations are working to develop less costly fluid flow field plates. Approaches include the molding of carbon composite materials and the evaluation of various coated metal and metal alloy materials. The ultimate choice of flow field material and manufacturing process remains to be determined, but it seems very likely that several approaches will ultimately be successful in achieving the transportation market cost targets.

5. Summary

Substantial progress toward the commercialization of solid polymer (or PEM) fuel cells has been made. Commercial prototype fuel cell powered buses are available. The power density targets for the fuel cell stack for automotive applications have been met. The remaining issues are largely manufacturability and cost issues, which must be addressed in conjunction with automakers and the developers of ancillary engine components.

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