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Solid polymer fuel cell developments at Ballard

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Abstract

Over the last several years, Ballard Power Systems has significantly advanced the state of solid polymer fuel cell (also known as PEM fuel cell) technology, having demonstrated substantial increases in power density, effective operation on air as the oxidant, and satisfactory operation on synthetic gas streams analogous to those obtained from the reforming of hydrocarbon fuels. More recently, Ballard has focussed its attention on the development of fuel cell systems and the demonstration of fuel cells in practical applications. Ballard has developed a fuel cell system which accepts pressurized hydrogen and air and produces d.c. power. The system contains the fuel cell stack, a fuel/air management sub-system, a heat management system, a water management sub-system and a control system. The unit is started by pushing a single button and delivers power within five seconds. The 3–5 kW units have been shipped to several organizations around the world for evaluation. Ballard has also begun a program to demonstrate the operation of a 30 ft transit bus powered entirely by a 105 kW fuel cell system, fueled by gaseous hydrogen. The bus is to be operational within one year. Ballard has also demonstrated the operation of a brassboard fuel cell system operating on methanol as the fuel. The system contains a reformer and an air compressor, as well as heat and water management sub-systems and an integrated control system.

Introduction

Recent advances in the performance [1] of the solid polymer fuel cell (known generically as the proton exchange membrane or PEM fuel cell) have stimulated significant interest in this technology throughout the world. Workers in the field have reported significant reductions in catalyst loading [2–4] and increased understanding of the importance of water transport in electrolyte membranes and fuel cell structures [5–8].

At Ballard Power Systems, the activities have been largely focused on translating this increased understanding of the fuel cell into useable fuel cell stacks and power systems. A further focus of these activities has been the demonstration of the potential of this technology in real applications. This paper presents an overview of recent developments in the fuel cell stack, hydrogen/air systems, and in methanol/air systems, as well as a description of a program now underway to develop and demonstrate a transit bus fully powered by solid polymer fuel cells.

Fuel cell stack developments

The performance breakthrough in this technology resulted from a combination of developments in stack hardware by Ballard [1] and the availability of a new

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developmental membrane from Dow Chemical [9]. The initial version of the Dow membrane was very thin and somewhat difficult to handle. Later versions of the membrane exhibit substantially improved handling properties while providing somewhat diminished performance [1].

Ballard has incorporated the latest version of the Dow membrane into a production fuel cell stack, which consists of 35 active cells and an integral gas humidification section. The dimensions of the stack are 10 in × 10 in × 18 in (25.4 cm × 25.4 cm × 45.7 cm) and the active electrode area is 36 in^2 (232 cm^2) per cell. A photograph of that stack is presented in Fig. 1. Typical performance data for the production stack operating on hydrogen and air are presented in Figs. 2 and 3. Figure 2 shows the current/voltage behaviour of the stack operating on hydrogen and air each at a pressure of 30 psig (3 atm.). At an air pressure of 50 psig (4.4 atm.) the stack will produce slightly more than 5 kW. If air is replaced by oxygen at 30 psig (3 atm.), the stack will produce over 10 kW of power. Figure 3 shows the uniformity of the performance of the 35 cells making up the stack at two different currents.

The physical properties of the Dow membrane are somewhat different from those of Nafion, the membrane electrolyte which had been the *de facto* standard for this technology. This required that the fuel cell stack be redesigned to assure proper gas sealing and to provide an operating environment conducive to long operating life time with the Dow membrane. Both of those objectives have now been achieved.

The gas permeability of the membrane/electrode assembly has been found to be a good indication of the reliability of the membrane in operation. A significant increase in the gas permeability with time suggests that the membrane is suffering some progressive damage which will ultimately result in failure. Ballard has now demonstrated stack operation in excess of 2000 h with the Dow membrane with no increase in the gas permeability over that which is characteristic of the fresh membrane. At the same

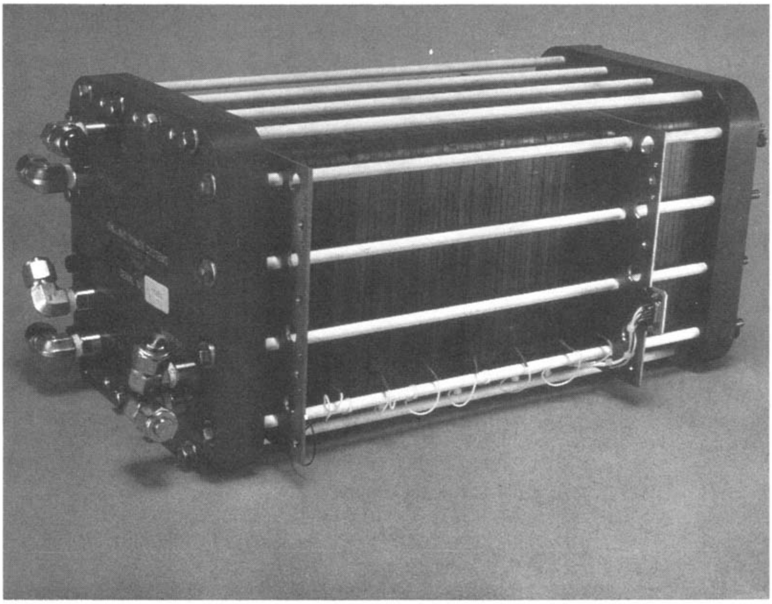

Fig. 1. A 35-cell solid polymer fuel cell stack.

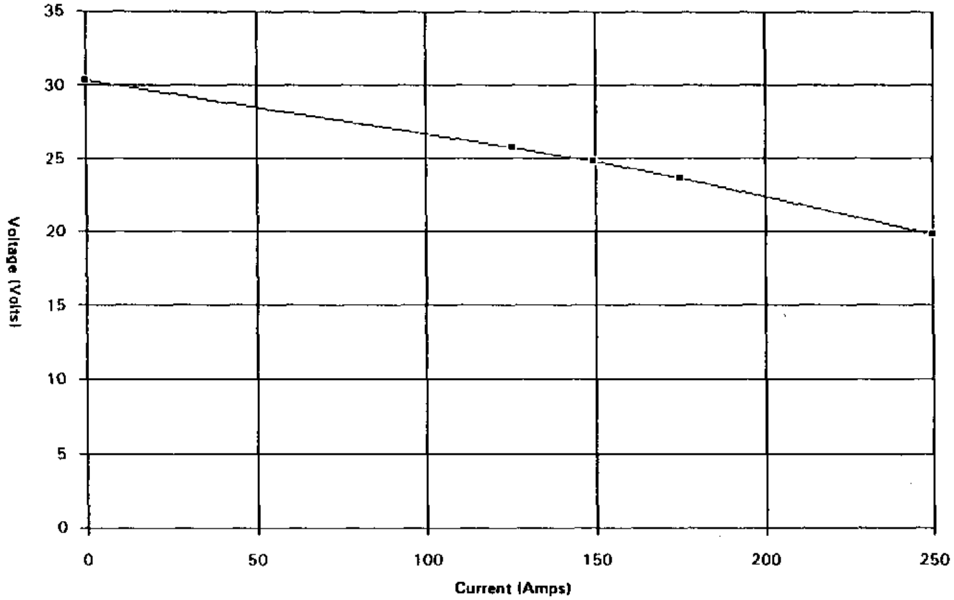

Fig. 2. Polarization curve for 35-cell stack, 232 cm^2 electrode area, H_2/air at 3 atm./3 atm. and 1.5/2.0 stoichiometry, 70 °C.

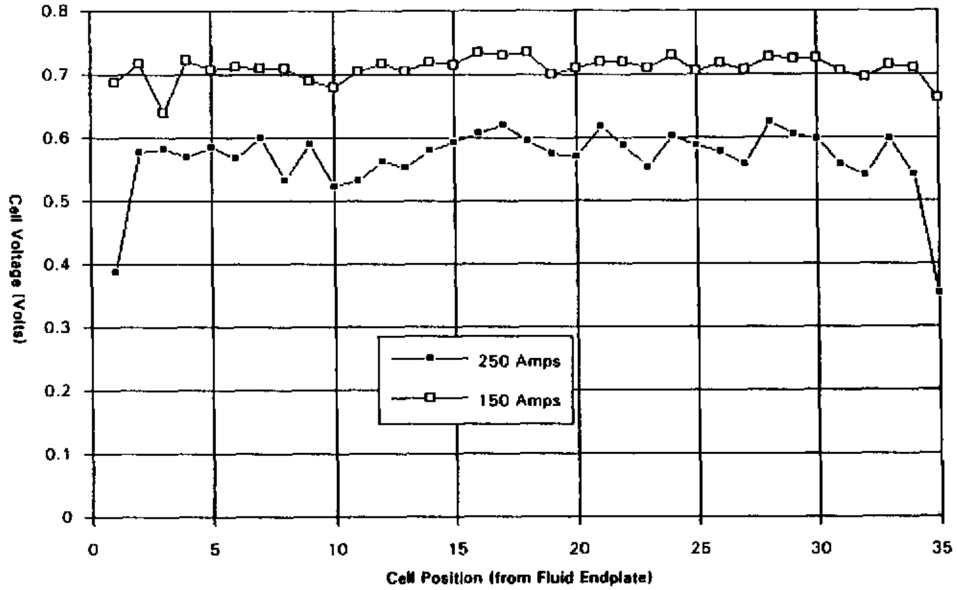

Fig. 3. Cell-to-cell consistency in 35-cell stack, 232 cm^2 electrode area, H_2/air at 3 atm./3 atm. and 1.5/2.0 stoichiometry, 70 °C.

time, Ballard has recently developed sealing technology which eliminates external gas leakage to a detection limit of 1 cc/min for the entire stack.

As part of its bus development program, which will be discussed below, Ballard has recently subjected one of its fuel cell stacks to the vibration protocol specified by MIL-STD-810E. This test simulated the vibration associated with operating the fuel cell in a city bus for 5000 miles (8000 km). The 35-cell production stack was vibrated in the longitudinal and vertical axes while the fuel cell was in operation. No change in fuel cell operation, internal gas transfer or external gas leakage was observed during these tests.

Hydrogen/air power system

In order to facilitate the testing of the fuel cell stack, Ballard has developed an integrated fuel cell system, based upon the 35-cell production stack. The system operates on pressurized hydrogen and oxidant (either air or oxygen) and includes sub-systems for gas control, product water collection, stack cooling, and system control. The parasitic electrical load due to these sub-systems is about 250 W.

A single push-button causes the control system to start the power system by opening the gas control valves, starting the coolant circulation and hydrogen recirculation pumps and monitoring the stack temperature and voltage. Within five seconds, the system connects the fuel cell power system to the external load. The control system automatically shuts the unit down when the operator touches the 'off' button or in the event of system overload or malfunction. The unit is shown in an exposed top view in Fig. 4.

While this unit was designed for room temperature operation, it was recently used to test stack operation at more extreme temperatures, as part of the bus

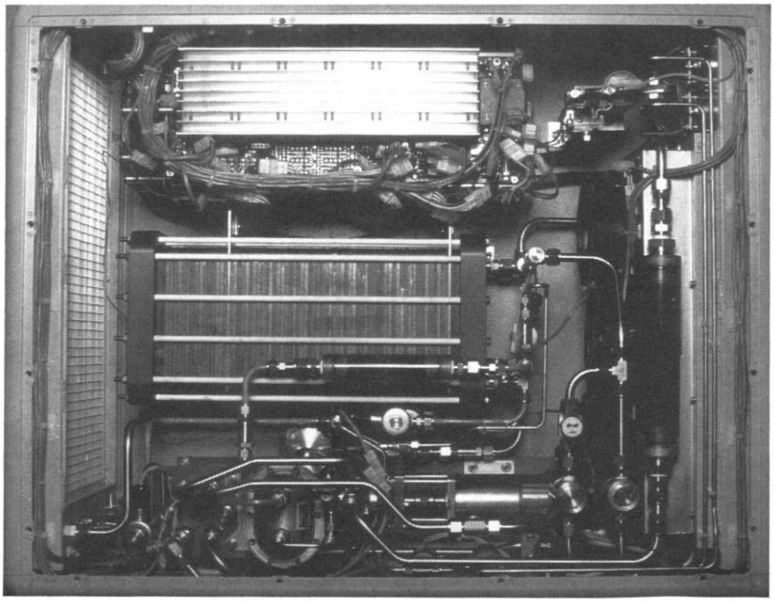

Fig. 4. Hydrogen/air system, exposed top view.

demonstration program. The system was cold soaked overnight at 3 °C in an environmental chamber. The system started immediately and by the time full load had been applied, 45 s after start-up, the system produced 50% of its rated power. In the 3 °C environment, it took the system about 15 min to achieve full operating temperature and power. That time could certainly have been shortened had the system been designed for low temperature operation. The system was subsequently operated in a 40 °C environment, as well.

Methanol/air fuel cell system

Ballard has now demonstrated a complete methanol/air laboratory brassboard fuel cell system. This system, which is largely assembled from components purchased from various suppliers, consists of a methanol reformer, a selective oxidizer to remove CO from the reformate gas stream, an air compressor, two fuel cell stacks operated in parallel, a voltage regulator, and control systems for the reformer and the fuel cell system.

To our knowledge, this is the first time a solid polymer fuel cell has been demonstrated to operate in conjunction with a methanol reformer and the first demonstration of a self-contained system demonstrating methanol in and regulated d.c. power out. The system was designed to produce a net 4 kW, but the purchased selective oxidizer was unable to sustain that power level. The purchased selective oxidizer was replaced with a prototype developed by Ballard which had been designed for a 1 kW throughput. With that unit in place, the system has been run for a number of three-hour tests at the 1 kW level, with no indication of performance decay.

Ballard is presently involved in the development of an improved reformer and system. The reformer will be significantly smaller than the unit purchased for the 4 kW brassboard and the selective oxidizer will be scaled to meet the needs of the system. The progress of this program will be reported elsewhere.

Fuel cell bus demonstration program

Ballard has begun a program to develop a commercial transit bus based upon solid polymer fuel cell technology. Phase 1 of this program is funded at a level of Cdn $4.84 million by the Province of British Columbia and the Government of Canada. This phase is 30 months in duration and will be completed in Mar. 1993.

The objective of Phase 1 is the demonstration of a commercial transit bus, fully powered by solid polymer fuel cells, which provides the same performance and driver acceptance as the diesel version of the same bus. The Phase 1 bus is to be based upon existing fuel cell hardware, to be fueled by hydrogen stored on-board as the compressed gas, and is to achieve a range of at least 150 km. The specific bus performance objectives are shown in Table 1.

The direction of this program is somewhat unusual in that, although it is largely funded by governments, control of the program and the allocation of funds is in the hands of a steering committee, chaired by a representative of the local transit company which will test the bus. The committee, with representatives from Canada, the US, and the UK, includes potential users, representatives of regulatory agencies, and academics. Ballard's objective in establishing such a steering committee was to create

TABLE 1

Bus performance specifications
Requirements (all with full seated passenger load)

Gradability	30 kph on 8% grade
Acceleration	1–50 kph in 20 s accelerate to and maintain 70 kph on level road
Start	start on 20% grade
Gross weight	9752 kg (21 500 lbs)

a program which would be driven by the demands of the market, rather than by technical targets.

Input from the committee has prompted three specific program choices:

(1) to select, as the test bed, a standard commercial bus, available as a diesel and licensed for transit applications;

(2) to power the bus entirely with fuel cells;

(3) to fuel the bus with hydrogen, rather than a hydrocarbon fuel such as methanol.

The commercial bus option was chosen to permit a direct performance comparison with the diesel version, to ensure that the bus could be licensed for transit applications, and to preclude any criticism that the bus chassis had been specially designed to accommodate the fuel cell system. The decision to use only fuel cells to provide motive power, rather than to use a hybrid battery–fuel cell system, was taken to eliminate any doubt that the fuel cell was, in fact, powering the bus and to explore the technical issues with such an option.

Compressed hydrogen gas had originally been selected as the fuel for Phase 1 to simplify the systems considerations and to focus the demonstration on the operation of the fuel cells rather than on a reformer. Discussions with potential users and regulators have demonstrated a clear preference for hydrogen as the on-board fuel rather than a hydrocarbon fuel such as methanol. The regulators see this choice as the only reasonable option for eliminating CO_2 emissions, whereas operators wish to avoid the capital cost, weight, and maintenance expense associated with having a reformer on-board each bus.

A sixteen-passenger, 21 500 lb (9752 kg) bus from National Coach has been selected as the test bed and is on order. Delivery of the bus is scheduled before the end of the year. The fuel cell power system will be based upon 21 of Ballard's standard nominal 5 kW stacks. These fuel cells are now being delivered to the bus program for integration into a brassboard power plant consisting of three 7-stack strings in parallel with the necessary fuel and oxidant delivery systems, cooling system, and control system. The fuel cell power system will ultimately deliver 75 kW to the wheels.

The power system brassboard is to be assembled by the end of Oct. and will be tested until the power system is installed in the bus in mid-1992. Testing of the bus is to begin in Aug. 1992 with Phase 1 being completed in Mar. 1993.

The layout of the bus is presented in Fig. 5. Note that the fuel cells are located at the rear of the bus, while the fuel tanks are located beneath the bus floor. The batteries located along one side of the bus provide starting power, as well as power for a 12 V control system, but provide no motive power. These batteries will be recharged by the fuel cell system and are completely analogous to the SLI battery in an automobile. The power budget for the bus system is presented in Table 2.

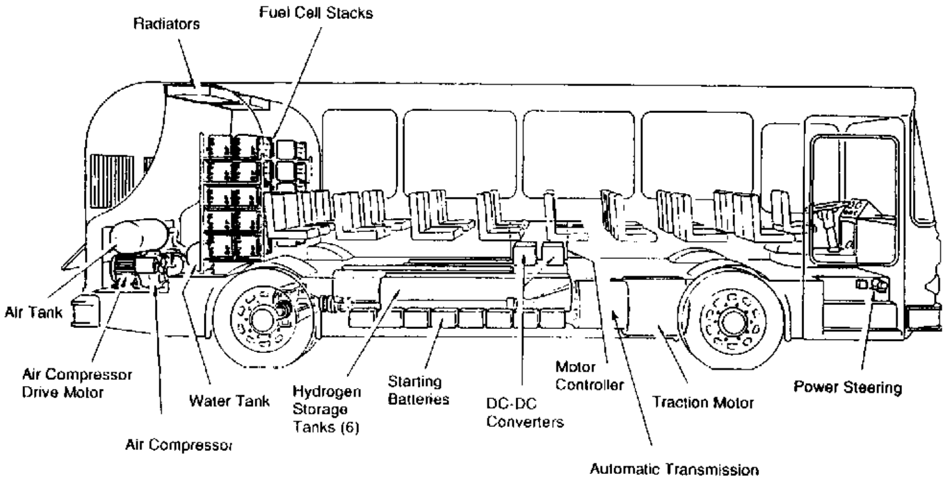

Fig. 5. Fuel cell bus system layout.

TABLE 2

Bus power budget

	Load	Duty cycle	Average	Fuel cell	12 V system
Traction	84	1	84	84	
Process air compressor	14.5	1	14.5	14.5	
Power steering and braking	1	0.5	0.5	0.5	
Lights, wipers, driver control	1.2	1	1.2		1.2
Cooling water pump	1.85	1	1.85	1.85	
Radiator fan	0.5	1	0.5		0.5
Lube oil pump	0.1	1	0.1	0.1	
Traction motor blower	0.75	1	0.75	0.75	
Control system	0.3	1	0.3		0.3
Safety system	0.02	1	0.02		0.02
Ethylene glycol pump	1	1	1	1	
			104.72	102.7	2.07

Total fuel cell power: 105.29 kW
Bus range at top speed (94 km/h) on level ground: 244 km
Bus range on simulated UMTA route: 150 km

On the assumption that the Phase 1 bus is successful, Phase 2 will involve improvements in range, based upon the incorporation of improved hydrogen storage technology and the use of more compact fuel cells and ancillaries. The size of the bus will also be increased to 40 ft.

Summary

Significant progress has been made in the development of solid polymer fuel cell stacks and systems and programs are now underway to demonstrate the potential commercial value of this technology for motive applications.

Acknowledgements

The achievements reported here are the results of the combined efforts of all of the many employees of Ballard Power Systems. The author also wishes to acknowledge the contributions of those employees of SAIC involved in the integration of the bus systems under sub-contract to Ballard.

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