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Polymer electrolyte membrane fuel cells for communication applications

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Abstract

An advanced portable power source using a 50 Watt (PPS-50) polymer electrolyte membrane cell EMFC) system was developed by Ball Aerospace under the US Army, Defense Advanced Research Project Agency (DARPA) and the Office Special Technology (OST) joint program. The PEMFC system was designed as required for commercial and military applications. The system as evaluated extensively under different environmental temperatures and humidity conditions. The thermal behavior and discharge performances of the PEMFC system at different discharge currents, temperatures and relative humidities were also investigated. The temperature range was from −10 to 50°C and the relative humidity (r.h.) from 10 to 90%. The PPS-50 system can provide a normal power output about 50 W at 12 V, while the peak power output can reach approximately 65 W (11 V, 6 A). The water production efficiency from the cathode was approximately 70%, and the residual 30% diffused to the anode side. The system was also used to power PRC-119 radios for communication applications, and it performed extremely well during the retransmission site test, operating continuously for over 25 h.

Keywords: Fuel cells; Polymer electrolyte membrane; Applications; Portable communications

1. Introduction

The US Army requires extremely lightweight, quiet, efficient and reliable power-sources for a variety of portable electronics and other applications in the modern battlefield. Polymer electrolyte membrane fuel cells (PEMFCs) are most favored as portable power supply devices, primarily because of their lightweight and high power density. At the present time, the best candidate for a high-energy power source for long-duration Army missions is the hydrogen/polymer electrolyte membrane fuel cell, in which hydrogen (tanked, metal hydride or chemical hydride) and oxygen from the air are combined to produce electricity, heat and water. A PEMFC will provide power indefinitely as long as it is supplied with fuel. The PEMFC power sources are also being developed for a wide variety of applications that now use batteries. These range from laptop computers to electric vehicles. Future man-portable power source systems will need to have a high power density and a long operating life and they must be small and lightweight. Using a lightweight PEMFC system as the portable source can reduce the physical burden on the carrier.

The following key areas need to be addressed to produce successfully the desired high-performance, lightweight, ambient temperature and pressure, fuel cell system:

1. thermal and heat transfer management;
2. water management;
3. environmental factors;
4. hydrogen storage conditions;
5. determination of the optimum stoichiometry of fuel and oxidant;
6. system integration for high-performance PEMFCs [1–7].

This paper addresses the performance of the PPS-50 system, as developed by Ball Aerospace, at discharge currents between 3.5 and 6 A (maximum power output approximately 72 W at 12 V) under the different environmental temperatures, and relative humidities.

The PPS-50 contains two fuel cell stacks connected by parallel, each of them with 18 single cells connected by series. The dimensions of the system are: 107 mm × 178 mm × 198 mm (4.2 in. × 7 in. × 7.8 in.) and the total

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weight is 2.95 kg (6.5 pounds). The system provides a user-friendly LCD interface for system start-up and shutdown. An RS-232 data port is available to status the system parameters and to provide atmospheric data to the user. Behavior of the system when used for communication applications is also reported.

2. Experimental

High purity hydrogen was used as fuel. The oxygen was taken directly from the environmental air by the internal air pump in the PPS-50 system. The environmental temperature and humidity were control within a Tenney Environmental Chamber, which was programmed through a computer with Linktenn II software. An Arbin Tester was used to control discharge tests. In order to get reproducible results, the time interval between tests were at least several hours or overnight to allow temperature and humidity to reach an equilibrium between the internal power system and the environment.

3. Results and discussion

The PPS-50 systems are designed to protect themselves from permanent failure by shutting off the load during some out-of-specification conditions or aborting the program in others. Constant current discharges at 3.5, 4 and 6 A were carried out to evaluate the PPS-50 system. The system was evaluated at all possible relative humidities and over a wide range of temperatures.

Fig. 1 shows the performance of the PPS-50 fuel cell system under different discharge currents at 20°C and 32% r.h. The PPS-50 is a 12 V fuel cell supply that is able to provide 60 W continuously and 70 W in bursts for a few minutes. As operating time and current increased, the membrane became more hydrated and stack performance improved significantly. The performance results obtained at relative humidities of 10, 40, 60 and 90% at 40°C and at the 4 A discharge current are almost identical (Fig. 2). The system was designed to be self-humidifying, and the

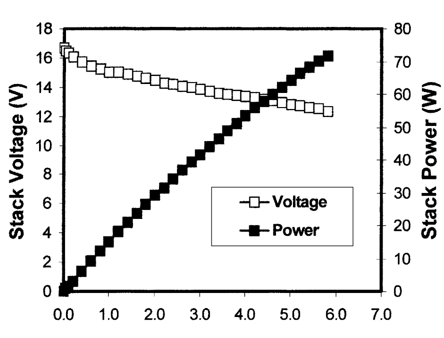

Fig. 1. Performance of the PPS-50 system at 20°C and 32% r.h.

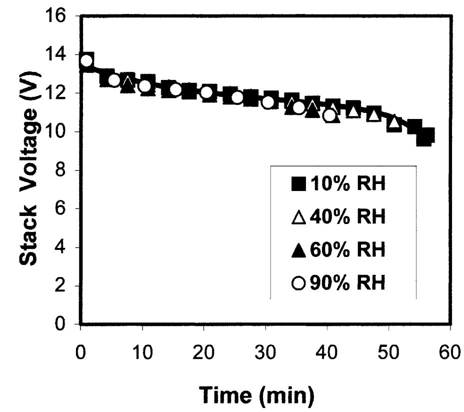

Fig. 2. Effect of relative humidity on the performance of the PPS-50 system at a constant discharge current of 4 A in an ambient temperature of 40°C.

environmental relative humidity seems to have no effect on the discharge performance of the system.

The effect of environmental temperatures over the wide range of +2 to 50°C was also tested to evaluate the discharge performance of the system at 60% r.h. This is shown in Fig. 3. At the beginning, the stack has a voltage of approximately 13.5 V for all the different environmental temperatures. As discharge time increases, the performance of the stack becomes significantly different at various temperatures. The performance at the lowest tested temperature (2°C) has the highest stack voltage and the voltage remain constant during the whole operating time. At 20°C or less, the long-term operating voltage can remain above 12 V. However, at 40°C or higher, the stack voltage drops so quickly that the PPS-50 System can only run for a short time because of the stack system overheating (i.e. when the internal fuel cell stack temperature gets higher than 65°C).

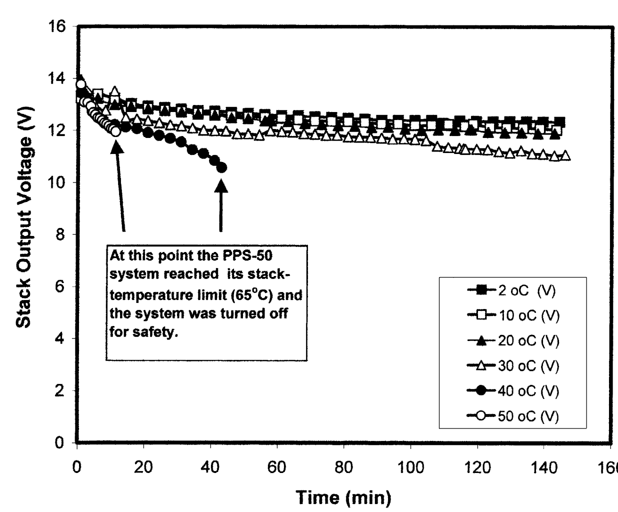

Fig. 3. Effect of ambient temperature on the performance of the PPS-50 system at a constant discharge current of 4 A in an ambient temperature of 60% r.h.

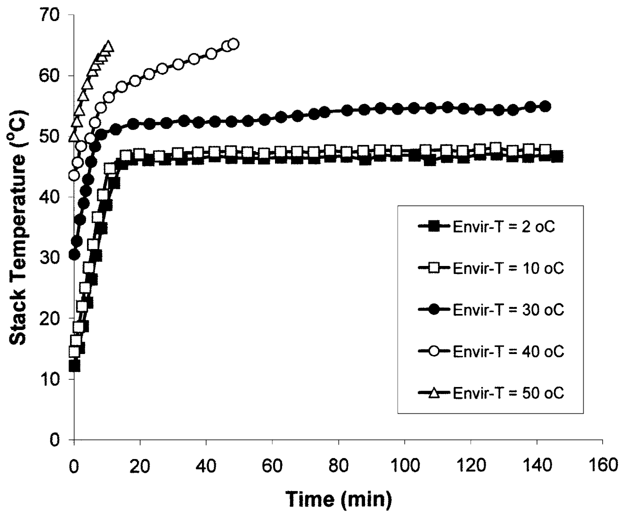

Fig. 4. Effect of ambient temperature on the internal stack temperature of the PPS-50 system at a constant discharge current of 4 A in an ambient temperature of 40°C.

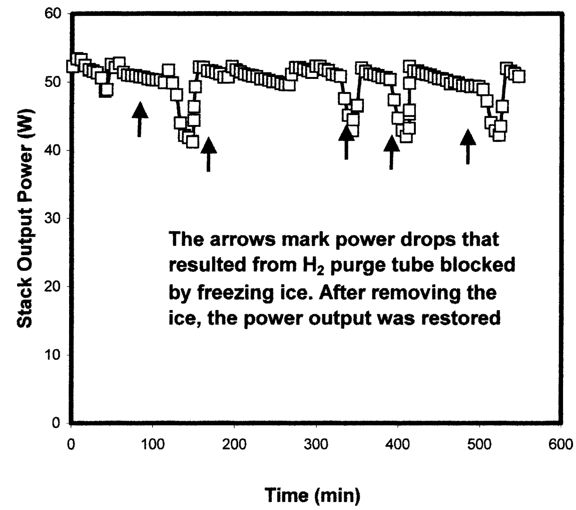

Fig. 6. Performance at constant discharge current of 4 A from a PPS-50 system in an ambient of −10°C.

Fig. 4 shows the fuel cell stack temperatures as a function of time at the different environmental temperatures and at 60% relative humidity. In general, the system performance is better at the low operating environmental temperatures, where heat, which is one of the products of the fuel cell reaction, is more readily dissipated. High discharge currents will generate more heat and Fig. 5 shows the stack temperatures at different discharge currents at 40°C and 40% r.h. ambient conditions for discharge currents of 3.5 and 4 A. The stack temperature increases very quickly and then remains at a constant level after about 10 min at 3.5 A The system demonstrates a good performance for 1 h at the 4 A discharge current before the cut-off temperature of 65°C was reached So the system performed very well at the 3.5 A discharge current, but heat generation is high at 4 A.

Operating the system at sub-zero temperature was also evaluated. Fig. 6 shows the plot of stack voltage output versus time at 4 A constant current discharge during the −10°C experiment. Because the hydrogen purge tube was blocked by freezing ice, several voltage drops can be seen on the voltage–time curve in the figure. However, after removing the ice from the hydrogen purge tube the stack voltage recovered. The system operated at −10°C for more than 9 h.

Our experimental results showed that the PPS-50 system performance was excellent at different environmental temperatures and humidity. The temperature range was from −10 to 50°C. The system performance is independent of environmental humidity. At lower temperatures, the bipolar PEMFC stack shows better discharge performance.

Fig. 7 shows the long-term 6 A discharge current performance of the PPS-50 system at 20°C and 32% r.h. The

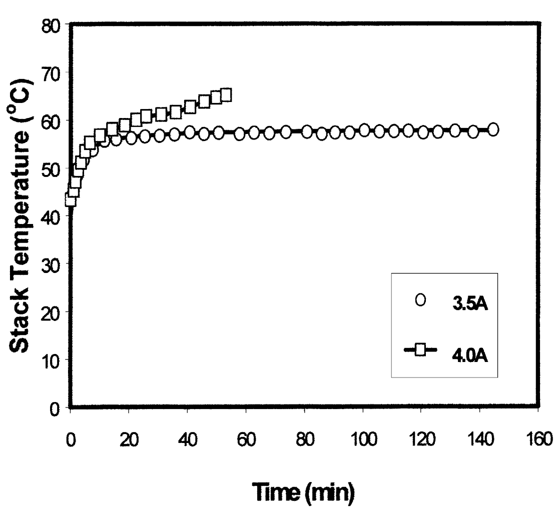

Fig. 5. Effect discharge current on the internal stack temperature of the PPS-50 system in an ambient of 40°C, 40% r.h.

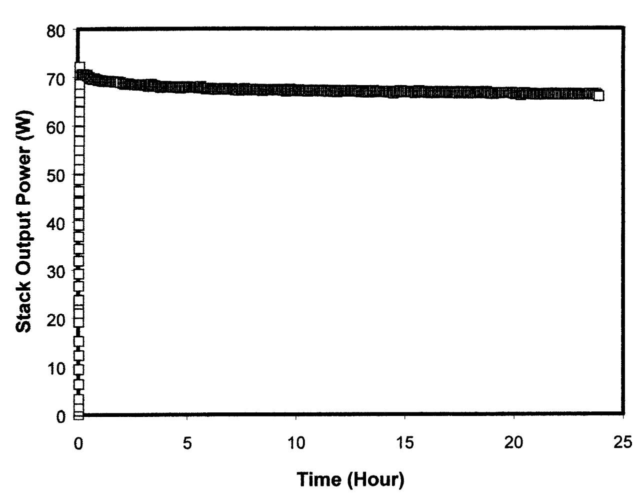

Fig. 7. Performance at constant discharge current of 6 A from a PPS-50 system in an ambient of 21°C, 22% r.h.

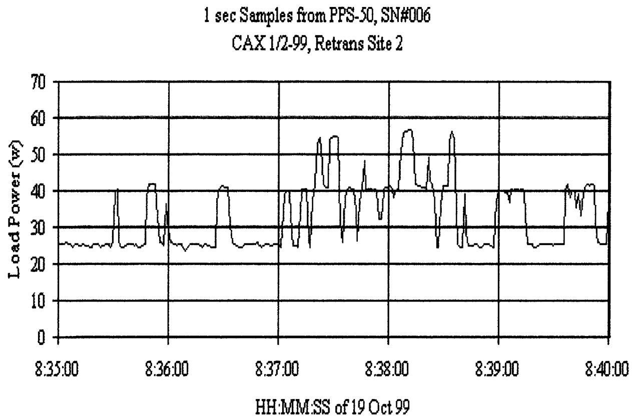

Fig. 8. Load profile over a 5 min period with the PPS-50 system powering two radio nets.

system can provide a constant power output of approximately 65 W, which is higher than the designed normal power output of 50 W. As the operating time and current increase, the membrane became more hydrated and stack performance improved significantly.

The PPS-50 W system was also tested in field exercises by the Marine Corps at 29 Palms Marine Base in October 1999. The PPS fuel cell system was used for communication applications and to power nine PRC-119 radios (system capacity is 12 radios simultaneously) and a laptop computer for 20 h with no glitches in power. The fuel cell system tracked changes in power demand fast enough to avoid any brownout conditions for the radio. Fig. 8 shows load power logged over a 5 min period from a PPS-50 powering two nets of PRC-119 radios. Two idling nets drew 25 W, one idle net and one transmitting net drew 40 W, and both nets transmitting drew an average 55 W.

The fuel cell power systems are also able to respond in real-time to the load. Fig. 9 shows the load power for the 24 h of operation on the PRC-119 radios. It shows that there was light radio traffic through the night with a large increase at the morning of 19 October 1999. The gap between 11.00 and 13.00 h is because the computer was logging data from a PPS-100 instead of the PPS-50. The end of the curve drops to about 3.5 W when the eight net radios were shut down. All of the exercises were accomplished in good time and the PRC-119 radios were operated properly.

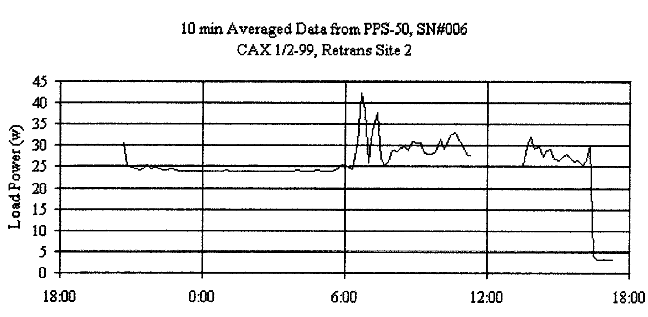

Fig. 9. Load profile over a 24 h period with the PPS-50 system powering two radio nets.

This field test, conducted by the US Marine Corps, demonstrated that small fuel cells are a reliable, lightweight and cost-effective means of providing power for military applications. The fuel cells performed extremely well during the retransmission site test, operating continuously for over 25 h. The use of fuel cells in place of traditional batteries can reduce the cost of energy by up to 80%.

4. Conclusions

The thermal behavior and discharge performances of the PPS-50 system at different discharge currents, temperatures and relative humidities were investigated. In general, the system performance is better at low operating environmental temperatures, because the heat generated from the fuel cell reaction is more easily dissipated to the environment at lower temperatures. Our tests showed that the PPS-50 system performance was excellent at different environmental temperatures and humidity, the temperature range tested being -10 to 50°C. The system performance is independent of environmental humidity.

The PPS-50 fuel cell system was also used successfully in field exercises by the Marine Corps, a test which demonstrated that small fuel cells are a reliable, lightweight and cost-effective means of providing power for military applications. The fuel cells performed extremely well during the retransmission site operating continuously for over 25 h. To use fuel cells in place of traditional batteries can reduce the cost of energy up to 80%.

Understanding the performance characteristics of stack systems is clearly important for the realization of the optimum cost/weight/volume/performance ratios. The results of this study advance the development of the PEMFC stack system for practical power for the soldier and future combat system applications.

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