RECENT ADVANCES IN METAL HYDRIDE FUEL CELL TECHNOLOGY FOR UPS/EMERGENCY POWER APPLICATIONS

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ABSTRACT

Novel metal hydride fuel cell (MHFC) technology has been scaled up and demonstrated in 320 W stacks and 500 W systems. This enables a 1500 W stack building block for UPS/emergency power applications. Stacks and the associated balance of plant can be integrated into prototype systems for telecom and other applications. Future power development activities are aimed at stacks achieving a specific power of 150 W/kg. The durability of the MHFC technology has been demonstrated by the operation of several multicell stacks in operation in excess of 7,000 hours. Metal hydride fuel cells offer a practical, low cost approach to power systems for UPS/emergency power applications. Charge storage characteristics of the metal hydride active material provide for special features including instant start, fuel hot swap capabilities, good low temperature performance, and inherent bridging and transient handling capabilities. The MHFC is also comprised of low cost components, including non-noble metal catalysts, carbon powders, nickel meshes, plastic binders, and plastic stack components. Fabrication and manufacturing of the MHFC involves conventional processing equipment similar to that used in commercial battery manufacturing. The MHFC offers an excellent opportunity for low cost fuel cell stacks addressing the serious cost issues facing the fuel cell industry.

INTRODUCTION

Fuel cells are power generation devices that operate on hydrogen and oxygen to provide clean, efficient electrical power with only water and heat as byproducts. Fuel cells can provide power for a variety of applications including portable, stationary, and transportation. Unlike battery systems, fuel cell systems have separate energy storage and power generation components, making them well-suited for backup power applications. With fuel cells, the runtime can be extended for many hours or days by adding inexpensive hydrogen cylinders rather than investing in extensive battery banks[1,2]. Fuel cell backup power system products are available and have recently been used in hurricane and blackout conditions to provide critical power[3]. However, further advances are needed in cost, durability, and reliability to achieve widespread introduction into the backup power market. The metal hydride fuel cell (MHFC) offers a practical, low cost approach for fuel cell backup power systems[4]. This paper reports on recent progress on the development of higher power stacks, improved durability, and demonstration in systems.

METAL HYDRIDE FUEL CELLS

The metal hydride fuel cell is a fundamentally new approach to fuel cells that avoids the traditional noble catalysts and incorporates charge storage materials in the electrodes[5,6]. These materials provide for intrinsic energy storage yielding unique performance features, including instant start, fuel hot swap capabilities, power bridging and transient handling, and good low temperature performance.

The MHFC uses low cost materials, readily available components, and a manufacturable design. Catalysts, carbon/graphite powders, and PTFE binders are combined and rolled or pressed onto nickel mesh substrates to form electrodes. Fuel cell stack components, such as plastic frames and endplates, can be injection molded. Fluid distributors located inside the MHFC are comprised of readily available plastic meshes and screens. Initial bill of materials and manufacturing analyses indicate that MHFC stacks can be manufactured at low costs with equipment, processes, and plants similar to those used in commercial battery manufacturing[7]. MHFC technology is especially promising for applications in the range of 1-100 kW, where the material cost advantage over conventional fuel cell types will be substantial.

FUEL CELL STACK SCALE UP

Our earlier prototype MHFC stacks were based on cells with 60 cm^2 active area electrodes. These were suitable to demonstrate the technology in applications up to 100-200 W. In the past year, we have developed scaled up stacks based on electrodes with 250 cm^2 active area that are suitable for applications up to 1 kW and beyond with further improvements in power density now under development. Figure 1 shows a stack of 16 cells with 250 cm^2 active area capable of delivering about 320 W, with our standard electrode design.

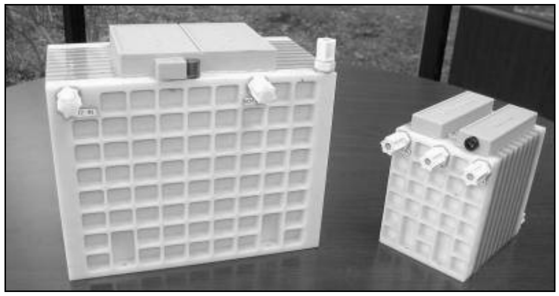

Figure 1: 16-cell MHFC stack with 250 cm^2 active area in comparison to earlier 16-cell prototype stack with 60 cm^2 active area

The operating voltage and power output as a function of current are shown in Figure 2 for a scaled up 250 cm^2 stack in comparison to the power performance for a comparable smaller stack of the previous design shown in Figure 3. In a simple monopolar design, it is difficult to maintain the same current density capability due to the increased resistive losses caused by the increased electrode area. However, we were able to achieve a 4-fold scale up in electrode area with comparable current densities by improved current collection and improvements in fluid flow uniformity within cells and in cell-to-cell flow distributions. This development was aided by the utilization of computational fluid dynamics modeling and analysis developed in recent PEM fuel cell development programs. We also have developed experimental techniques to simulate and observe critical fluid flow patterns that aid in this development. Improved uniformity of electrode processing was also critical to the success of this development.

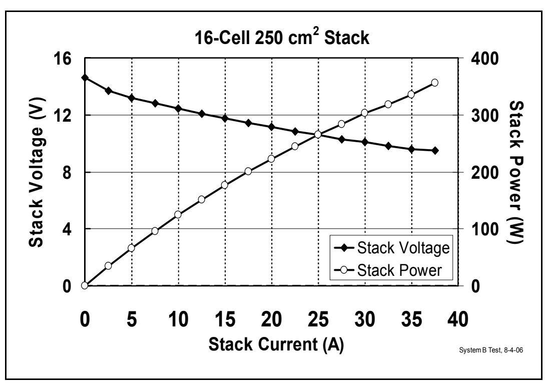

Figure 2: Power performance of 16-cell 250 cm^2 stack showing operation at 320 W

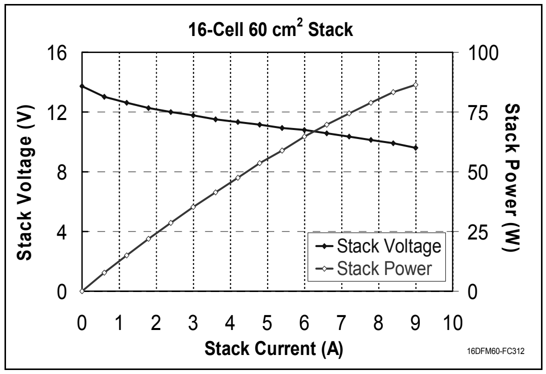

Figure 3: Power performance of 16-cell 60 cm^2 stack showing operation at 80 W

The scaled up 250 cm^2 stack yielded improved specific power and power density due to packaging efficiencies for this larger stack as shown in Table 1. The specific power and power density can be increased further by adding more cells to the stack. An 80-cell stack can deliver 1.6 kW with a specific power of 61 W/kg and a power density of 62 W/L. Note that this power density approaches that of PEM fuel cell stacks in UPS/emergency power systems being demonstrated by others.

Table 1: Stack Comparison

	80W 16-Cell, 60 cm^2 MHFC Stack	**320 W 16-Cell, 250cm^2 MHFC Stack**	**1.6 kW 80-Cell, 250 cm^2 MHFC Stack***	**5 kW PEM Fuel Cell Stack****
Power (W)	80	320	1600	5500
Weight (kg)	1.8	6.0	26.4	45
Volume (L)	2.0	6.6	25.7	70
Specific Power (W/kg)	44	53	61	122
Power Density (W/L)	40	48	62	79

*Projected.
**Estimated from public literature.

Further development is underway to improve the specific power of this 250 cm^2 stack platform to 150 W/kg or higher for stack building blocks of 1.5 to 5 kW, enabling overall backup power systems in the range of 1-100 kW. Larger stack building blocks on the order of tens of kilowatts are also possible.

Packaging development can reduce the stack volume by reducing the cell thickness and increasing the active area fraction of each electrode frame. We estimate that the stack weight can be reduced by 10-25% and the stack volume by 25-40%, enabling 80-cell, 250 cm^2 MHFC stacks with a specific power of 65-75 W/kg and a power density of 75-85 W/L. More substantial improvements are available through the development of higher power electrodes.

ELECTRODE POWER DEVELOPMENT

Increasing the intrinsic electrode power capabilities of the MHFC will reduce the number of cells required to meet a target power level, thereby increasing MHFC specific power (W/kg) and power density (W/L) metrics. The reduction in the number of components also results in lower costs as well as increased reliability. Current density, expressed in mA/cm^2 of electrode active area, provides an intrinsic indication of power capabilities. A MHFC stack and systems analysis has shown that operating current densities between 250 and 400 mA/cm^2 on a large-scale stack level will provide highly competitive MHFC products for UPS/emergency power applications[7].

Figure 4 shows results from a promising electrode combination achieving 250 mA/cm^2 at 0.6 V in comparison with the 150 mA/cm^2 achieved with standard electrodes, as shown in Figures 2 and 3. This and other promising electrode combinations will be selected for future builds of large multicell stacks with 250 cm^2 active area. In the case of the 80-cell 250 cm^2 stack described in Table 1, increasing the operating current density to 250 mA/cm^2 corresponds to increasing the stack power density from 62 W/L to 103 W/L. Similarly, the stack specific power increases from 61 W/kg to 102 W/kg.

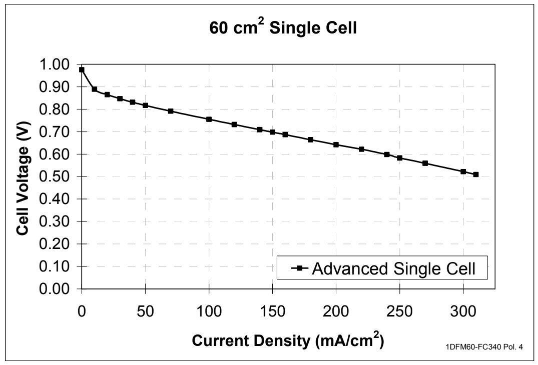

Figure 4: Power performance of 60 cm^2 single cell showing 250 mA/cm^2 current density capability

More fundamental studies on electrode materials are carried out in 10 cm^2 single electrode testing using a half-cell test apparatus. This allows quicker testing of a large number of combinations. Recent work has focused on the air electrode, which dominates the kinetic losses in fuel cell devices. Very promising new results have shown the capability to deliver 400 mA/cm^2 at the same voltage where standard electrodes previously delivered 150 mA/cm^2. With comparable improvements in the metal hydride anode, this could enable the development of 250 cm^2 stacks of 80 cells with a specific power and power density in excess of 160 W/kg and 160 W/L before packaging optimization.

DURABILITY

Durability of MHFC stacks is initially evaluated using continuous run operation on the lab bench. Over the last two years, the demonstrated durability of MHFC stacks has increased from 1,200 hours to over 7,000 hours, as shown in Figure 5. This indicates that the fundamental materials and structures of the MHFC are relatively durable and have significant potential for long life. Additional tests are being run using intermittent load profiles in order to assess intermittent life. Future tests will include load profiles and test protocols for specific customer applications. Intermittent life has been evaluated at a systems level and two 50 W demo systems have successfully operated intermittently for 6 months (more details in next section).

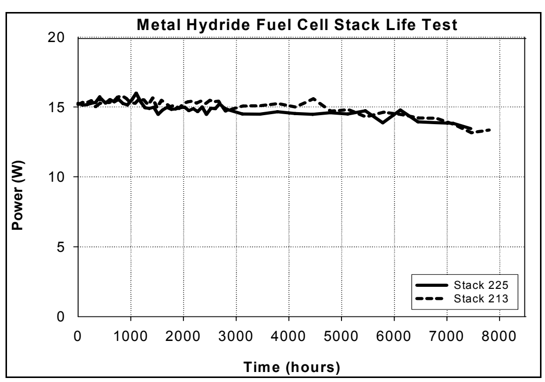

Figure 5: Life test plot for MHFC stacks showing more than 7,000 hours of operation

SYSTEMS DEVELOPMENT

MHFC systems consist of the following subsystems: 1) Hydrogen, 2) Air, 3) Electrolyte, 4) Controls, and 5) Power Conditioning. The hydrogen subsystem delivers the fuel to the MHFC. The air subsystem feeds ambient air to the MHFC to provide it with oxygen. The electrolyte subsystem provides water management and thermal management for the system. The controls subsystem serves as the “brain” for the entire system. A sample MHFC system layout is shown below in Figure 6.

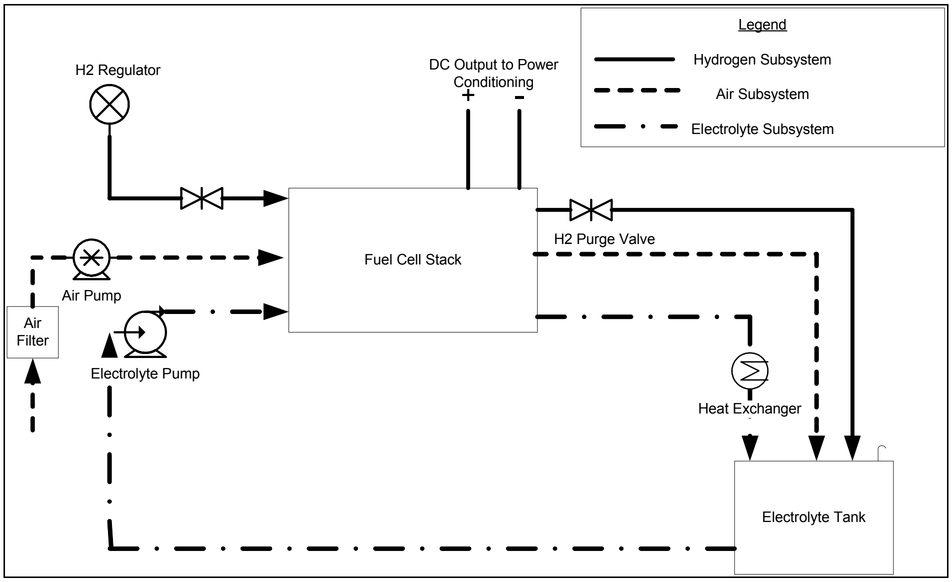

Figure 6: Sample MHFC system layout

Initial systems work was performed on two 50 W systems. These 50 W systems included MHFC stacks and subsystems installed into enclosures with LCDs for testing and demonstration. The systems provided 12 V DC output and were connected to either a portable car inverter or a commercial 300 W UPS backup system to provide AC output (the battery was removed from the UPS system and the fuel cell was connected in its place). The MHFC systems powered external loads, such as a TV, portable DVD player, and an aquarium pump/filter/lighting system. The two 50 W MHFC systems were intermittently operated from July 2006 to February 2007. These systems successfully demonstrated the operation and features of the Ovonic MHFC. The typical duty cycle for these systems was about three hours, but ranged from a few minutes to about 10 hours. It should be noted that during this period of testing, ambient air was used and no air filtration was performed. During this period of seven months, about 500 hours of intermittent runtime was accumulated by the two systems. The systems were started up and turned off about 200 times each over the course of normal operation, testing, and maintenance.

During the operation and testing of the 50 W systems, opportunities for improvements were identified, including system robustness, accessibility, and portability. Based on user feedback, one of the 50 W systems was reconfigured into a more robust and transportable system, as shown in Figure 7. Hydrogen fuel canisters were mounted into the system for a more integrated approach. Unlike previous systems, the entire system subassembly could be lifted out of the enclosure for easy inspection and maintenance.

Figure 7: Portable 50 W system

In addition to the 50 W systems, 500 W systems were also developed, as shown in Figure 8. Two approaches were used for the construction and integration of the 500 W systems. These systems were installed into standard 23-inch and 19-inch rack mount enclosures. Initial integration of a 500 W system was performed using ten 16-cell 60 cm^2 stacks. The ten MHFC stacks were installed into a 23-inch rack mount enclosure along with the associated peripherals and electronics. The system was successfully built and operated at 534 W, as shown in the performance plot in Figure 9.

Figure 8: 500 W system

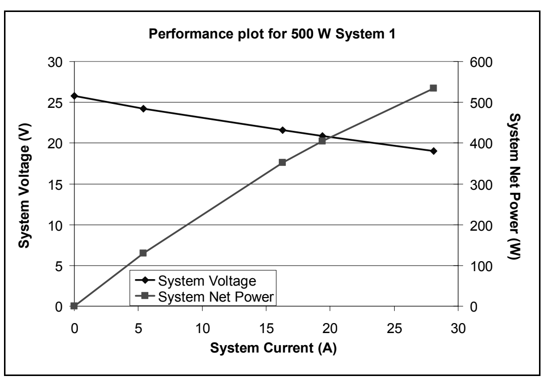

Figure 9: Performance plot for 500 W system using ten 60 cm^2 stacks

The integration of the next phase of 500 W systems was performed using two 250 cm^2 stacks per system. One of the key advantages of using fewer stacks was the reduction of the amount of fluid manifolding and wiring required. As a result, the system volume, system complexity, and parts count were reduced. A more compact 19-inch rack mount enclosure was used. The two stacks were able to provide over 700 W of gross power and 555 W of net power, as shown in the performance plot in Figure 10. The integration of the 250 cm^2 stacks into the 500 W system marked a key technological milestone; MHFC stacks were scaled up over 400% in active area and system operating power was increased by one order of magnitude from 50 W to 500 W.

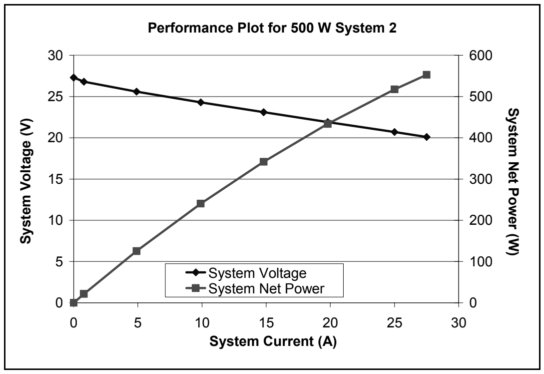

Figure 10: Performance plot for 500 W system using two 250 cm^2 stacks

The power performance metrics of the two 500 W prototype MHFC systems are shown in Table 2 in comparison to a commercially available fuel cell emergency power system utilizing PEM fuel cell stacks. On a systems level, the scaled up 250 cm^2 stacks led to a 37% savings in weight due to the reduced number of components required. The scaled up stacks also provided for improved packaging efficiency enabling the use of a narrower and shorter 19-inch rack instead of the 23-inch wide rack used in the first system. Even in this smaller enclosure, there was significant empty volume inside the enclosure, providing further opportunities for packaging efficiency. The reduced complexity also provided improved manufacturability and reliability.

Table 2: Comparison of Prototype 500 W systems with 60 cm^2 and 250 cm^2 stacks

	500 W MHFC System with 60 cm^2 Stacks	**500 W MHFC System with 250 cm^2 Stacks**	**5 kW System Based on Four 250 cm^2 Stacks of 80 cells***	**5 kW PEM Fuel Cell Backup Power System****
Power (W)	500	500	5000	5000
Weight (kg)	61	38	300	227
Volume (L)	117	84	450	451
Specific Power (W/kg)	8.2	13.2	17	22
Power Density (W/L)	4.3	6.0	11	11

*Projected.
**Taken from public literature.

We have performed an engineering analysis of a prototype 5 kW UPS/emergency power system complete with balance of plant, power conditioning, and enclosure. A system based on four scaled up 250 cm^2 stacks provided promising results as shown in Table 2. This shows the viability of the MHFC technology for UPS/emergency power applications in the range of 1-100 kW. Further improvements in stack power performance will provide for more attractive system weights and volumes, and especially pave the way to economically viable costs even in low volume production.

We are currently developing a 1.5 kW stack with a specific power target of 150 W/kg and have plans to scale up to 5 kW stack hardware. Utilization of 150 W/kg stacks would enable lighter and more compact systems on the order of 35 W/kg and 15 W/L. Larger stack building blocks on the order of tens of kilowatts will provide increased capabilities for even higher power systems.

SUMMARY

Metal hydride fuel cells incorporate a low cost, manufacturable approach with unique performance advantages, including instant start, good low temperature performance, and intrinsic energy storage capabilities. Significant recent developments in metal hydride fuel cell technology include:

- Scale up of stacks from 60 cm^2 to 250 cm^2 active area, creating a strong fundamental building block for higher power systems in the 1-100 kW range
- Development of higher power electrode technology, enabling future stacks to have power densities and specific powers over 100 W/L and 100 W/kg, respectively
- Demonstration of increased durability exceeding 7,000 hours operation
- Demonstration of 500 W systems with complete balance of plant

Progress in MHFC development has enabled the technology to approach the specific power and power density ranges of comparable PEM fuel cell technologies at both stack and overall systems levels. An initial systems analysis has shown that existing MHFC stack technology can fit into the packaging envelope of a commercially available 5 kW fuel cell UPS system and that further developments will result in considerably more compact and lighter systems. Work is underway to develop a 1.5 kW stack with 150 W/kg that will accelerate the development of low profile systems with higher power capabilities and increased power densities for extended run time backup power applications.

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ACKNOWLEDGEMENTS

The author gratefully acknowledges the contributions of: George Burke, Dennis Corrigan, Nathan English, Mihaela Glavan, Chad Kotarba, Arthur Leong, Franklin Martin, Peter Merle, Srinivasan Venkatesan, and Hong Wang. Ovonic Fuel Cell Company would like to thank the State of Michigan (MPSC) and the U.S. Army (TARDEC) for their support with our systems and stack development activities.