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Power assisted fuel cell

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Abstract

A hybrid fuel cell demonstrated pulse power capability at pulse power load simulations synonymous with electronics and communications equipment. The hybrid consisted of a 25.0 W Proton Exchange Membrane Fuel Cell (PEMFC) stack in parallel with a two-cell lead–acid battery. Performance of the hybrid PEMFC was superior to either the battery or fuel cell stack alone at the 18.0 W load. The hybrid delivered a flat discharge voltage profile of about 4.0 V over a 5 h radio continuous transmit mode of 18.0 W. © 1998 Elsevier Science S.A.

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1. Introduction

Due to their high energy density, fuel cells are being actively investigated for use in portable electronics and communications equipment. While the continuous power capabilities of Proton Exchange Membrane (PEM) fuel cells are good, their response to instantaneous power demand is relatively poor. The PEMFC often requires up to 5 min to reach an operational steady state at a constant power load, during which individual cells of the stack become highly polarized. This polarized state is detrimental to the PEMFC stack. In many instances involving instantaneous power increases, the PEMFC's operating potential does not recover. This translates into fuel cells alone having great difficulty handling periods of high power pulses. The development of power assistance for PEM fuel cells is therefore of great interest.

Boulder Technologies developed Thin Metal Foil (TMF) lead–acid cells capable of extremely high power output with excellent capacity maintenance [1]. Additionally, these cells exhibit flat discharge profile at all currents, and are capable of very rapid recharge.

The utilization of such lead–acid cells in the power assistance of fuel cell stacks would allow for a system that has the energy density advantage of fuel cells and the high power output capability of lead–acid cells.

2. Experimental

All testing was conducted with Techware Automated Battery Cycler (ABC). The ABC is capable of constant power cycling to a maximum of 5.0 A. During testing, the operating voltage and current were recorded at every change of 0.1 V. This record increment guaranteed good data fit.

The 25.0 W PEM fuel cell stack of six cells with a nominal potential of 4.0 V is shown in Fig. 1. The stack utilized static ambient air to supply the reactant oxygen and to cool the stack through external heat sinks. Zero grade (99.999%) compressed hydrogen, regulated to 1 psig, was the fuel. The stack, dead ended, was installed with a purge device which provided for open air purging for 1 s every 5 min. This prevented the build up of contaminants that eventually reduce the stack's performance.

The TMF lead–acid cells used in the hybrid were obtained from Boulder Battery. The cylindrical cells utilize spirally wound electrodes of thin metal foil with active material. The electrodes are electrically separated via a glass separator wetted with sulfuric acid electrolyte. The cells are sealed in a plastic case with positive and negative contacts at opposite ends of the cell. The cell dimensions, excluding the current end busses, are 2.27 cm in diameter and 7.12 cm in length—providing a cell volume of approximately 28.7 cm^3. Cell weights range from 78.9 to 81.7 g. The TMF lead–acid cells, rated at 4.0 V and 1.2 Ah, are

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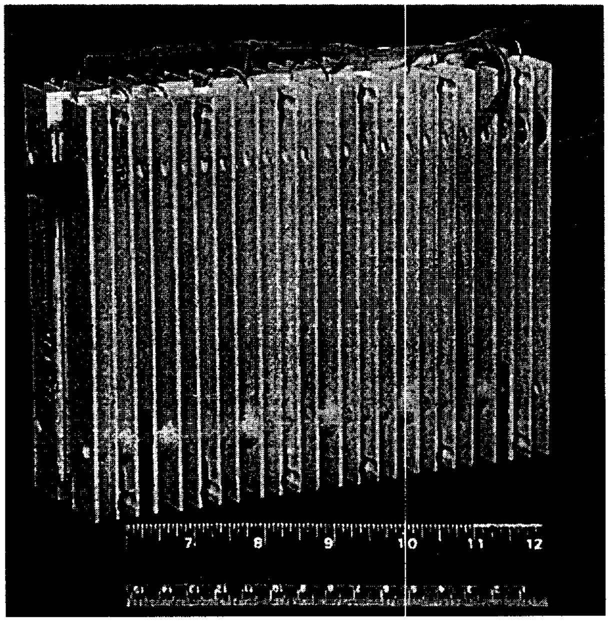

Fig. 1. 25 W PEM fuel cell stack.

capable of 8.0 kW/kg peak power density and recharge time of less than 7 min [1,2].

Two lead–acid cells were connected together in series to form a two-cell battery assembly. The total weight and volume of the battery was 160.7 g and 60 cm^3. This assembly was connected in parallel to the PEMFC stack to form the hybrid. At the start of all tests, the lead–acid cells were fully charged with a constant current two-step process of 1.0 A to 2.6 V, then 0.1 A to 2.6 V.

All testing was conducted at ambient room temperature (23–25°C). Initially, the limit of the PEMFC stack alone at

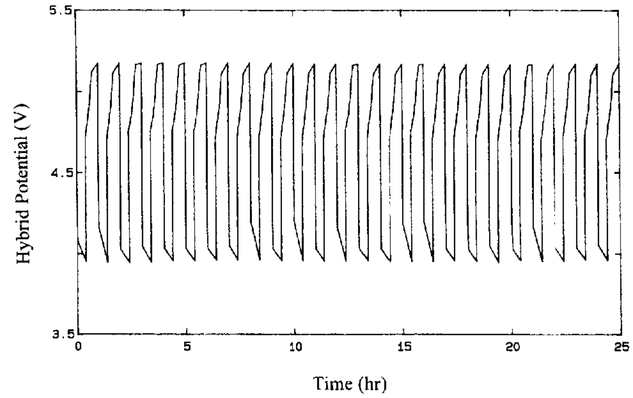

Fig. 3. The hybrid discharge curve. Discharge cyclic regime of 3.0 min transmit (18.0 W) followed by 4.5 min receive (2.5 W).

18.0 W (transmit) continuous power load was quantified. Performance of the hybrid was then measured at various radio simulation transmit and receive durations. The transmit:receive ratios tested included 3:4.5, 6:9, 12:18, and 24:36. Each ratio represents a cyclic regime of transmit duration in minutes followed by receive length in minutes. For example, the 3:4.5 ratio represents a cyclic regime of 3 min transmit (18.0 W) followed by 4.5 min receive (2.5 W). Following these tests, the lead–acid assembly alone and the hybrid with the lead–acid were tested at 18.0 W continuous discharge. Finally, the actual effects of the lead–acid assembly on hybrid performance were measured. In these tests, the hybrid was initially intact at the start. At specific times into each run of continuous transmit, ranging from 15 to 1.5 min, the lead–acid assembly was electrically disconnected from the stack. At this point, the PEMFC stack alone was powering the load.

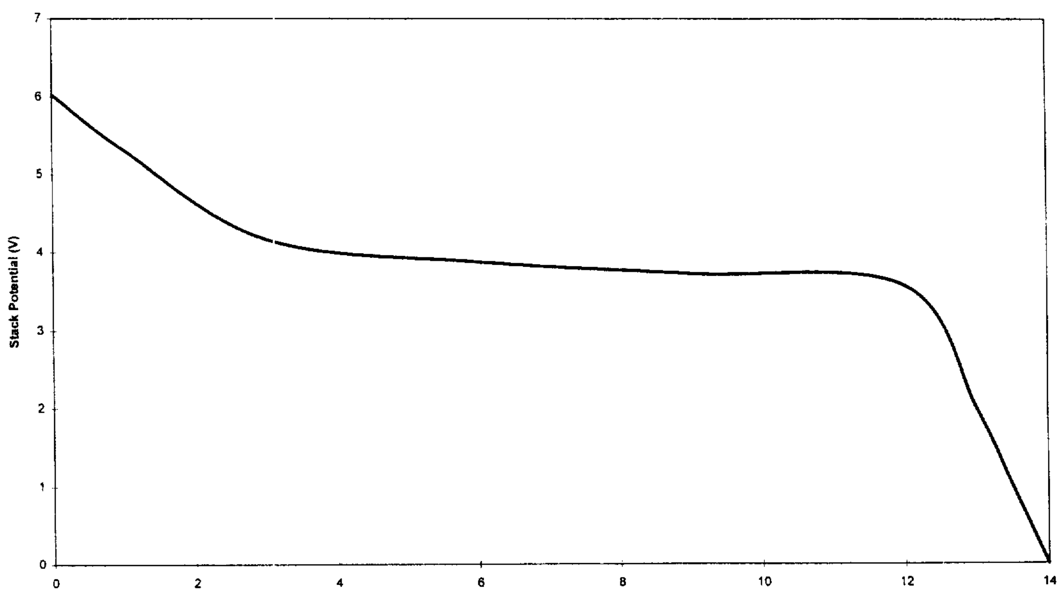

Fig. 2. 25 W PEMFC stack. Transmit (18.0 W) continuous discharge.

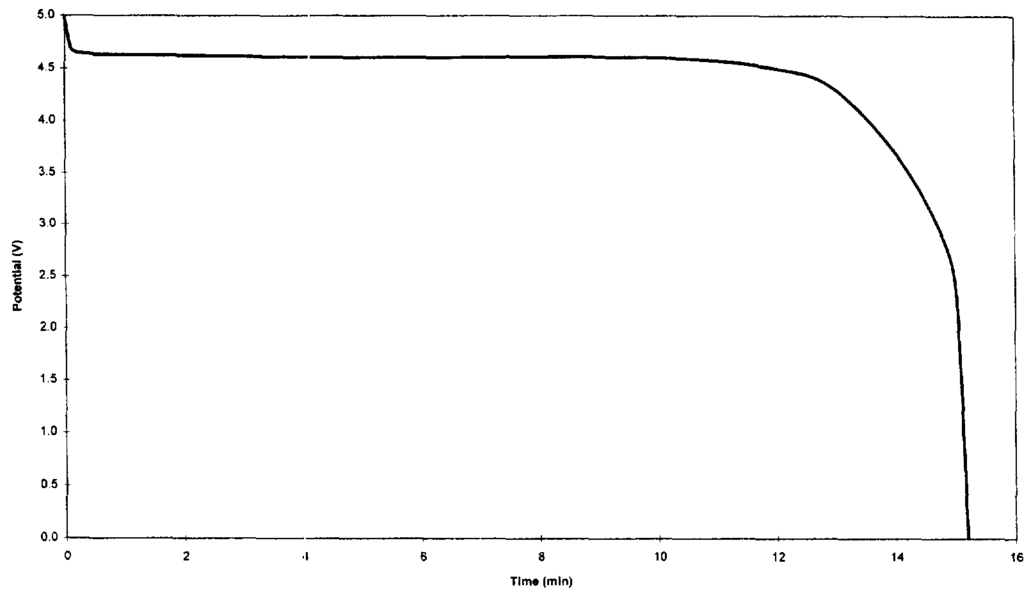

Fig. 4. The lead–acid 2-cell assembly discharge curve. Continuous transmit (18.0 W) discharge.

Throughout all tests, the operating potential, current, and internal stack temperature were measured and recorded.

3. Results

The 25.0 W PEMFC stack by itself could not power the high load pulse of high/low power cyclic regime. This is shown in Fig. 2. Fig. 2 displays performance of the stack alone during continuous transmit (18.0 W). This represents a worst case scenario. The operating stack potential dropped immediately. After 14 s, the potential fell rapidly to 0 V.

The hybrid successfully powered various pulse power load simulations. The load simulations included transmit:receive ratios of 3:4.5, 6:9, 12:18, and 24:36. Fig. 3 is typical of the results. Once stabilized, the operating potential was observed to be relatively flat, especially during transmit (18.0 W). Throughout all runs the operating voltage never dropped below 3.9 V.

Fig. 4 shows the performance of the lead–acid assembly alone during continuous 18.0 W (transmit) discharge. During this 18.0 W discharge, the average current drain was approximately 4.0 A for an output of approximately 0.98 Ah. Within 14.70 min the operating potential fell to 3.0 V cut-off.

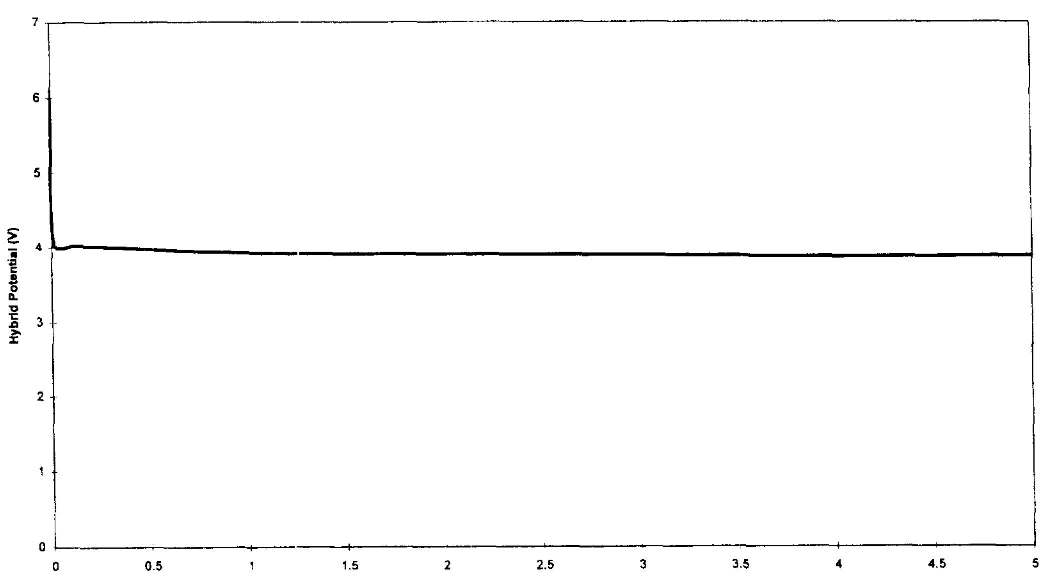

Fig. 5. The hybrid discharge curve. Continuous transmit (18.0 W) discharge.

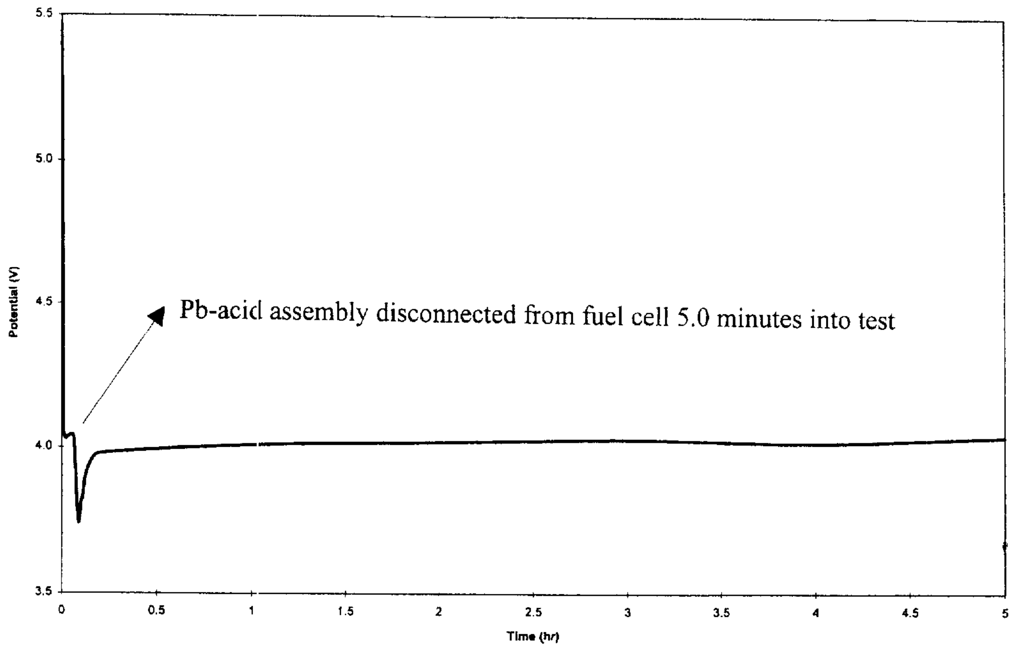

Fig. 6. Continuous transmit (18.0 W) discharge. Typical successful run where the lead–acid assembly is disconnected from fuel cell at specific minutes into test.

Fig. 5 displays the hybrid performance during continuous 18.0 W (transmit) discharge. During the 5 h run, the discharge profile was flat and the potential never dropped below 3.0 V. The operating potential remained constant at approximately 4.0 V.

The hybrid was successfully in operating continuous transmit (18.0 W) discharge load; whereas, both the PEMFC stack and the lead–acid assembly alone, could not. An attempt was made to determine to what extent the lead–acid assembly is no longer required for PEMFC stack assistance. Five tests were run. In each test, the hybrid initially was intact at the start. At specific times into the continuous transmit (18.0 W) discharge, ranging from 15 to 1.5 min, the lead–acid assembly was electrically disconnected from the stack. At this point, the PEMFC stack alone powered the regime. As short as 2.5 min in the test,

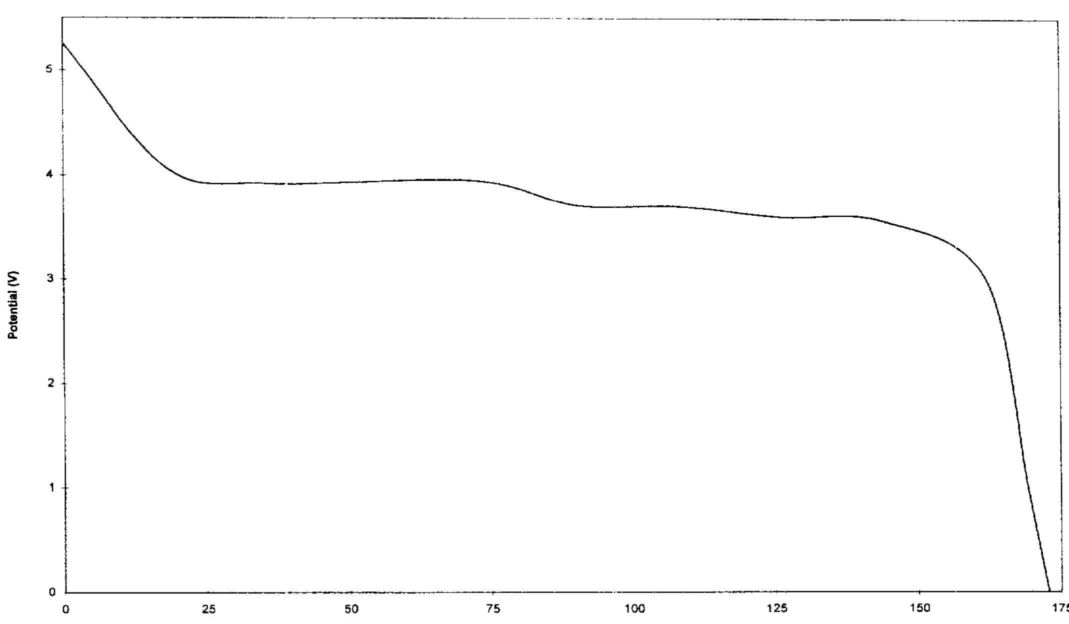

Fig. 7. Hybrid 18.0 W (transmit) continuous discharge curve. Lead–acid assembly disconnected from fuel cell 90 s after start of test.

the PEMFC stack alone continued to successfully power the 18.0 W continuous discharge. In each successful run, the operating potential immediately dropped when the assembly of lead–acid cells was disconnected. Within 2–5 min, the operating voltage of the PEMFC stack increased to the stable value of approximately 4.0 V. Throughout the successful tests, the operating potential never dropped below 3.5 V. Fig. 6 is typical of the four successful runs.

When the lead–acid assembly was disconnected form the hybrid 1.5 min into the test (Fig. 7), the PEMFC stack failed to successfully power the 18.0 W (transmit) continuous discharge. Approximately 90 s after the removal of the lead–acid assembly, the stack operating potential fell below 3.0 V and rapidly to 0 V.

4. Conclusions

The 25.0 W PEMFC stack and the two-cell lead–acid battery assembly alone could not power continuous 18.0 W (transmit) constant power load. The hybrid fuel cell, however, was successful in powering the aforementioned load for 5 h. The hybrid also successfully powered various ratios of transmit (18.0 W) to receive (2.5 W) pulse loads. It is evident that during high power pulses, the battery assembly effectively assisted the PEMFC stack. At the low power periods, the PEMFC stack powered the load while also recharging the battery assembly for the next cycle. In this way, the hybrid delivered both high energy and high power density.

References

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