ZINC REGENERATIVE FUEL CELL POWERS AN INDOOR CELL SITE

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ABSTRACT

Lead-acid batteries and generators have been the only viable means of economically backing up telecommunications sites in the event of a commercial power failure. Zinc / air, regenerative fuel cells are emerging as a compelling alternative, providing extended backup power to cell sites. This technology provides DC power from the electrochemical process of oxidizing tiny zinc pellets into zinc oxide. The electrochemical process is reversed when utility power returns, regenerating zinc fuel pellets from zinc oxide. The process of discharge and recharge can be repeated indefinitely, like a rechargeable VRLA battery without chemical degradation under broader ambient temperature conditions.

This paper describes the performance of a Zinc Regenerative Fuel Cell (ZRFC) observed while backing up a complete cell site, built at Metallic Power's development laboratory in Carlsbad, CA. The conditioned space used for the test was outfitted with standard cell site equipment, including a rectifier, site controller, transceivers, combiners, duplexers and receive multicouplers. The prototype ZRFC consisted of a cell stack, a storage tank for the zinc fuel suspended in electrolyte, an electrolyzer, which regenerates the zinc oxide back into zinc pellets and the power electronics. These components were integrated into a single system. The evaluation consisted of simulating a number of short and long power outages over a 2-week period. The prototype ZFRC tested was 1.8 kW, 110 VAC output, tied to cell site.

The laboratory trials demonstrated that the ZFRC system could successfully pick up the load after a simulated power failure to provide uninterrupted power to the cell site equipment, and transition the load back to grid power when commercial power was restored. The prototype ZRFC system supported the full load for the design time that would be expected by the theoretical amount of zinc fuel in the tank. The system automatically and fully regenerated the zinc oxide into usable, stored zinc pellets after each discharge at the design rate. This paper describes the performance of a Zinc Regenerative Fuel Cell (ZRFC) observed while backing up an indoor wireless cellular site.

INTRODUCTION

The ZRFC [1] prototype unit consisted of 2 stacks of 12 cells each fluidically connected to a fuel tank. The regeneration unit is contained within the fuel tank. The basic fluid flow system is depicted in Figure 1. The Zinc fuel flows with the electrolyte from the tank to the stacks where the DC power is produced.

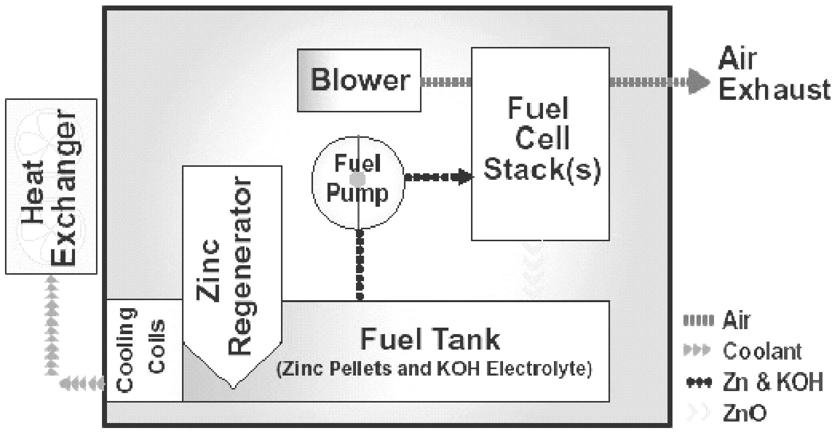

Figure 1. Fluid flow diagram of ZRFC

The DC output from the fuel cell is fed into power conversion electronics where it is boosted and converted to supply AC power. The system controller and I/O board for the fuel cell were designed and programmed by Metallic Power. The power electronics were primarily off-the-shelf components that were integrated together in house. The unit was set up as a classic standby AC UPS, where a transfer switch initiates the process of switching power when it senses power (AC) failure. Initial ride-through for the back-up system while the fuel cell starts up (<< 5 seconds) was handled by a small string of VRLAs. The system is shown in Figure 2.

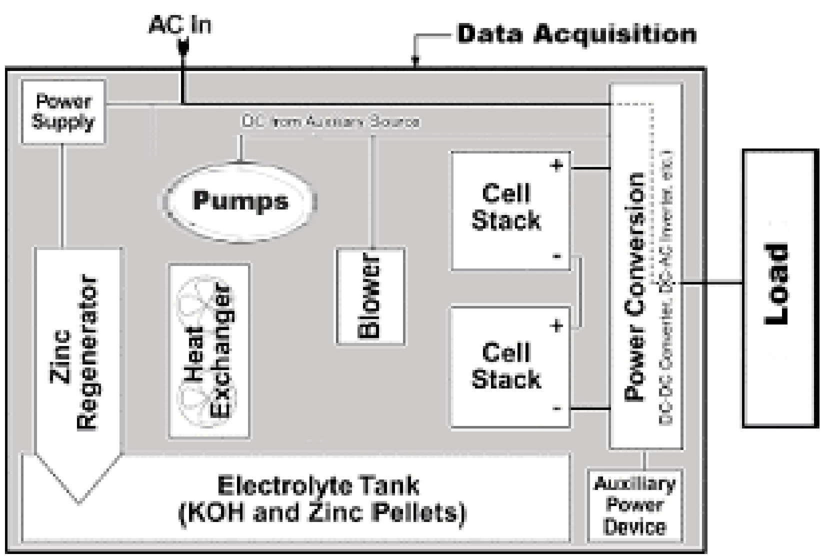

Figure 2. Electrical flow diagram of ZRFC

The remaining portion of this paper discusses the results obtained from the first ZRFC performing in an application of backing up a Cellular Radio site. This demonstration consisted of simulating power outages and tracking the performance of the ZRFC. It took place at the Metallic Power facility in Carlsbad, California, during the period of 8/12-23/2002. A picture of the unit in the lab running a bank of light bulbs (a load of over 1500 Watts) prior to the demonstration is shown in Figure 3.

Figure 3. Pre-demonstration testing in the Laboratory

SET-UP AND DEFINITION OF POWER FAILURE

The ZRFC system was connected to rectifiers powering a cell site as shown in Figure 4. The battery string was disconnected from the rectifiers. Shutting off line AC therefore meant that the rectifiers would power down unless the ZRFC AC UPS took over in-place of the line AC. Power to the radios is uninterrupted if the rectifier never produces a fault.

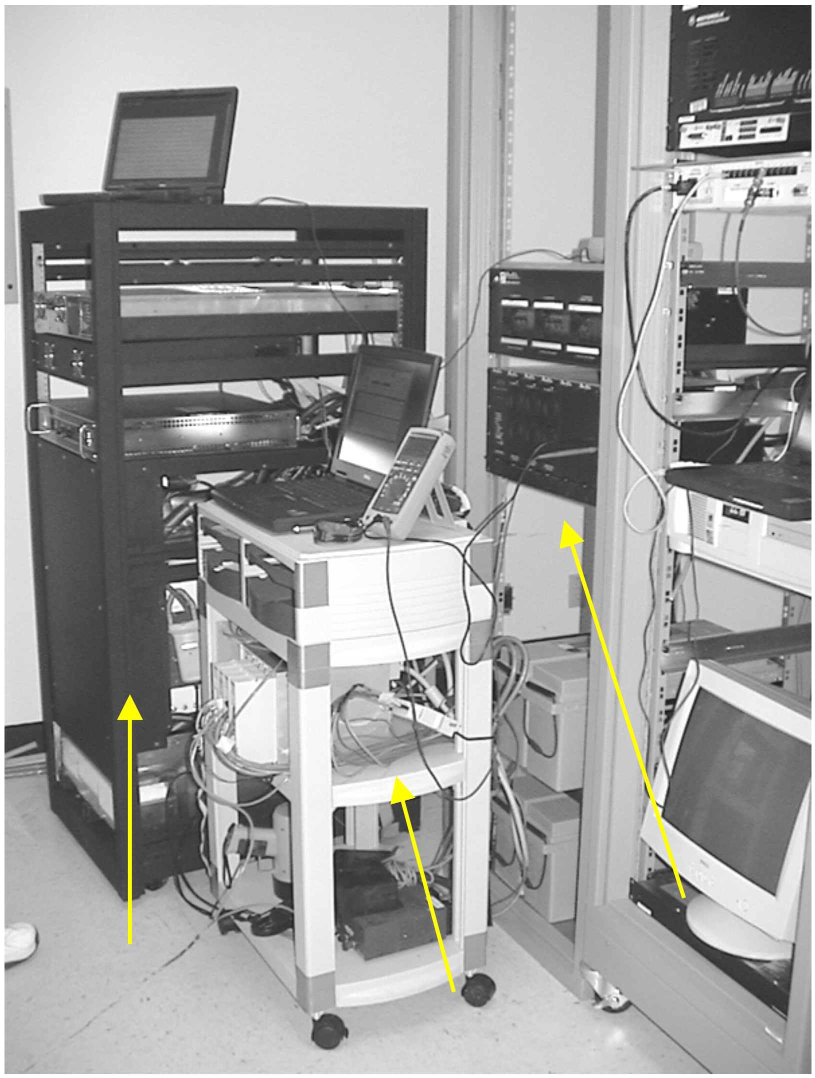

Figure 4. ZRFC, data acquisition cart and recitfier rack

SCHEDULE OF POWER OUTAGES

During the 2-week demonstration period, a number of power outages were simulated. There are 3 states that the system cycled between:

- Idle state – AC power is available and is running the rectifiers. The ZRFC UPS is fully charged and waiting for an outage
- Discharge state – AC power is failed and the ZRFC is running the rectifiers as a UPS.
- Regeneration State – AC power is available and is running the rectifiers. The ZRFC is regenerating the spent fuel using AC power. If there is fuel in the unit it can still switch to Discharge state if power fails.

A total of 4 full depth discharges, one 30 min discharge, and one 1-minute discharge, along with the corresponding regenerations are shown below.

Time	State
T0	Idle for 2 hours
T1	Discharge for 1 minute
T2	Idle for 1 minute
T3	Discharge for 30 minutes (partial)
T4	Regeneration back to full fuel
T5	Discharge (100%)
T6	Regeneration (100%)
T7	Discharge (100%)
T8	Regeneration (100%)
T9	Idle (short)
T10	Discharge (100%)
T11	Regeneration (100%)
T12	Idle (short)
T13	Discharge (100%)
T14	Regeneration (100%)

EXECUTIVE SUMMARY OF RESULTS

Discharge and regeneration performance of the fuel cell is given in the Table 1 and Table 2.

	Net Output			ZRFC Total Output			
Time	Discharge Duration	Current To Plant (@120 VAC)	Energy Delivered	Voltage (Ave)	Current (Ave)	Power (Ave)	Total Energy
T1	1 min	10 A	n/a	29 V	56 A	1620 W	n/a
T3	30 min	10 A	n/a	29 V	56 A	1620 W	n/a
T5	3.56 h	14 A	6000 Wh	27.5 V	81 A	2225 W	7.9 kWh
T7	3.51 h	12.5 A	5300 Wh	28.2	73 A	2060 W	7.2 kWh
T10	3.16 h	14.6 A	5500 Wh	27.3	87 A	2370 W	7.5 kWh
T13	3.3 h	14 A	5500 Wh	27.7	80 A	2220 W	7.3 kWh
Total	14.07 hours						

Table 1. Discharge performance summary

Time	Regeneration Time
T4	9 h
T6	30.5 h
T8	33 h
T11	31 h
T14	31 h
Total	134.5 hours

Table 2. Regeneration summary

The regeneration subsystem logged over 130 hours without any failures while producing the appropriate quantity and quality of Zinc pellets for use as fuel. The fuel cell stacks consistently produced over 2 kW for 14 hours without any intervention. The stack voltage dropped only about 1 V per hour during the discharge.

Other Notes:

- Loads were varied intentionally between discharges.
- Regeneration time during T4 appears proportionally larger. This was due to the fact that the demonstration started with a tank that was not 100% full or recharged.
- The total energy produced by the fuel cell varied by approximately 10% because there was 10% variability in the monitoring for the out of fuel condition. This was expected since the fuel gauge sensor had not been calibrated at that point to provide greater accuracy.
- The ZRFC did successfully carry the load throughout the whole test. However, there was a case during the T5 discharge cycle where the load was dropped. The root cause was traced to the improper sizing of the off-the-shelf inverter. The inverter produced a fault after 30 minutes of discharge in the T5 cycle when the fuel cell heat exchanger came on (~200 W AC load). This is discussed further in the next section.

- The temperature of the indoor site was raised during the regeneration cycle T6. Initially the room was controlled between 74 and 79 F and after it was controlled between 89 and 91 F. This was done to document that successful operation at higher temperatures is possible.

DETAILED DISCUSSION OF FINDINGS

Stack Voltage Data from the Discharges

Figure 5 is a voltage graph of the ZRFC through T3. The ZRFC carried the load without any problems. The small ripple in the voltage is due to the boost converter compensation while it responds to the AC load.

Figure 6 is a voltage graph of ZRFC for T5. The ZRFC voltages were consistent over the whole discharge. There was about a 1.08 V drop in the stack output per hour. This drop was compensated by an increase in current of 2.16 A per hour by the ZRFC to keep the power output constant.

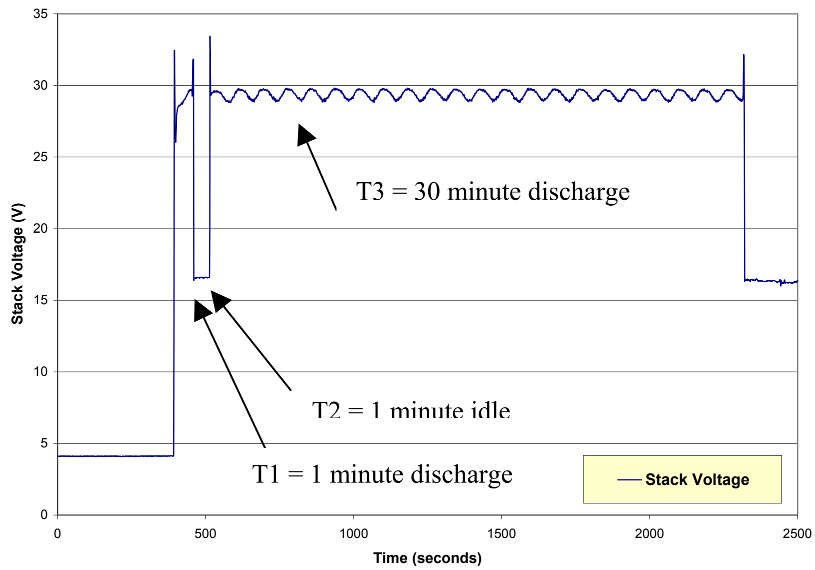

Figure 5. Stack Voltage for T1 – T3

The electrolyte temperature was added to the chart to explain the fault that occurred during the demonstration. The ZRFC shut down 31 minutes into the discharge when the fuel cell chiller first turned on and produced a fault in the inverter that was connected to the output of the ZRFC. The chiller consumes about 200 W of AC power. Plugging the heat exchanger into the AC main allowed the ZRFC to resume normal operation. The chiller had been plugged into the output of the ZRFC (along with the load). The fuel cell continued to function well.

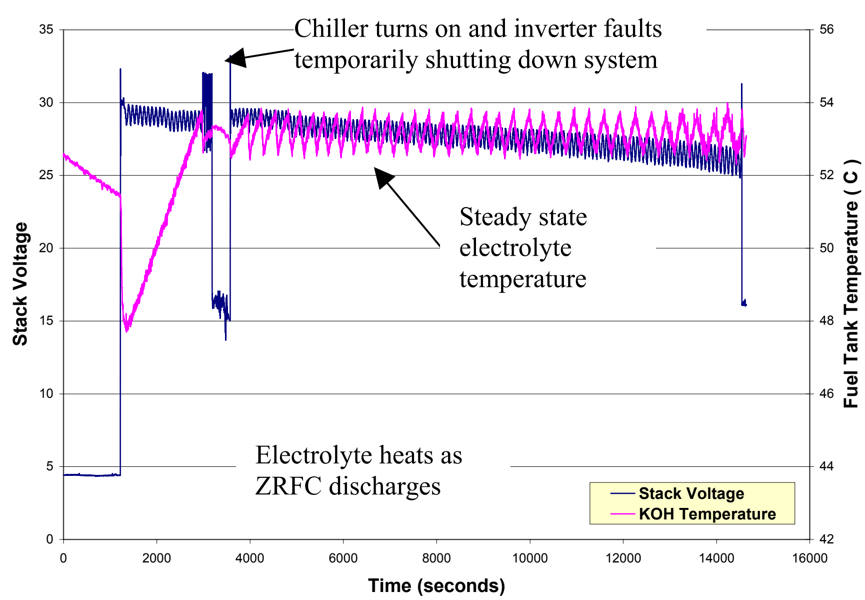

Figure 6. Stack Voltages and Electrolyte Temperature for Discharge T5

Figure 7 displays the voltage and current coming from the ZRFC during T7. Both show a very consistent output over the discharge. Current also exhibits a ripple in the same frequency as the voltage. Once again this is an artifact of the boost converter's control system as a result of providing AC.

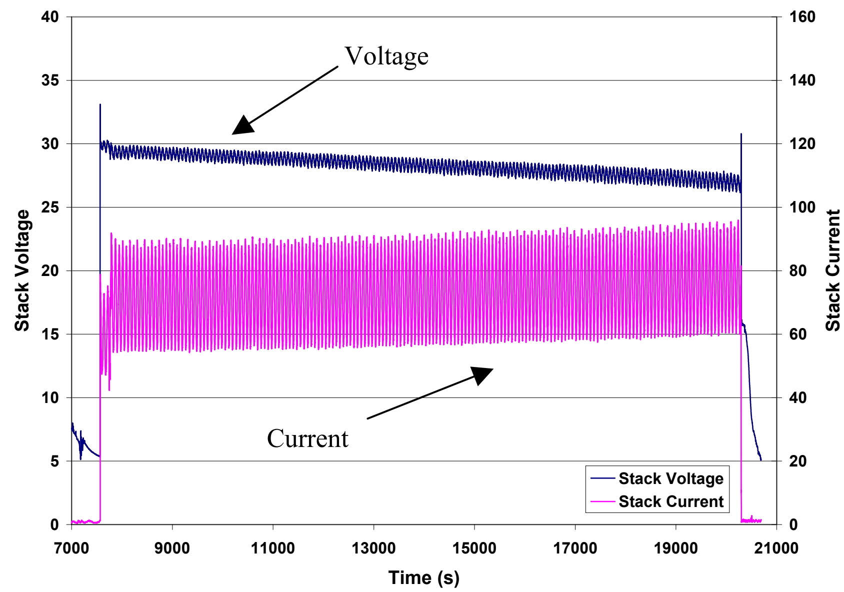

Figure 7. Voltage and current from ZRFC for discharge T7

Figure 8 displays the voltages for the last two discharges. The output of the fuel cell is very consistent between the two runs. The initial difference is attributed to the starting electrolyte temperature of the fuel cell. The slope difference can be attributed to the difference in the load between the two discharges.

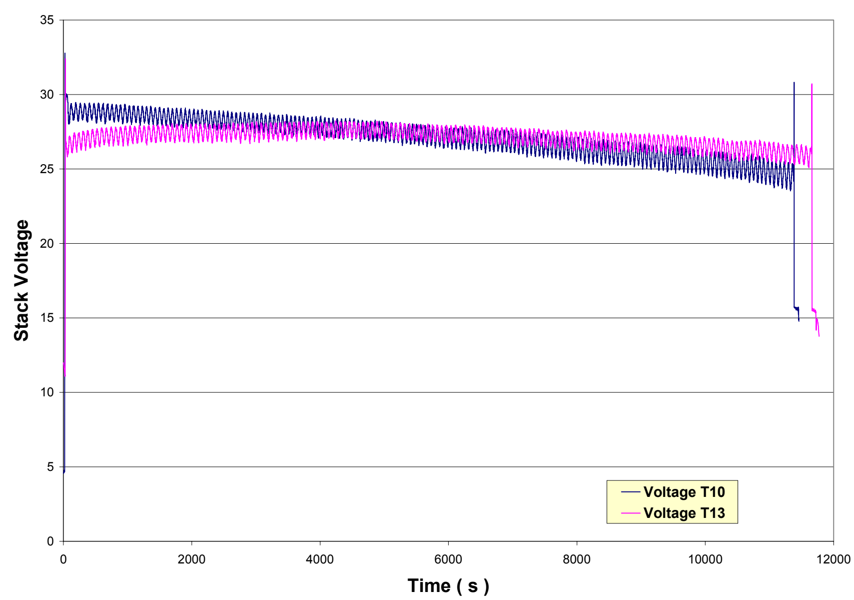

Figure 8. ZRFC Voltages from discharges T10 and T13

Regeneration

Figure 9 was taken after completing a regeneration cycle. The clear tank behind the stack has Zinc pellets at the bottom. The regeneration is a Metallic Power proprietary process based on reversing the chemical reaction that occurs during the discharge state. The regeneration rate is dependent on the size of the electrodes and power available for the reaction. This regeneration module was sized for 20 A common wall outlets.

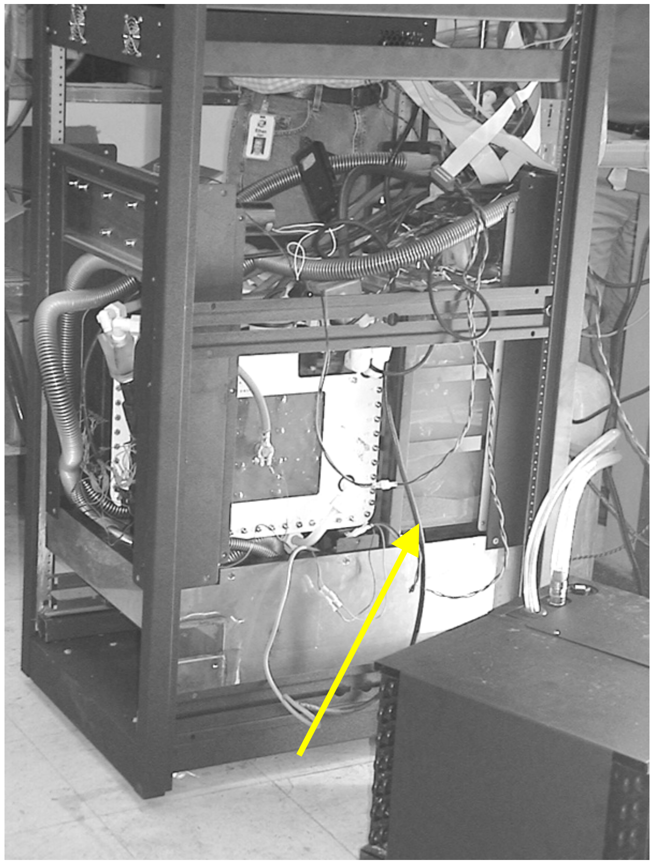

Figure 9. Close up of the ZRFC showing regenerated Zinc fuel in the clear tank

NEXT STEPS FOR METALLIC POWER

- Create a DC backup device that would connect directly to the DC bus similar to a string of VRLA batteries.
- Commence longer term testing in the field.

REFERENCES

1. Colborn, J, Smedley, S, "*Ultra-Long Duration Backup for Telecommunications Applications Using Zinc/Air Regenerative Fuel Cells*", Proceedings of Intelec 2001.