FUEL CELLS:
WILL FUEL CELLS BE REPLACING BATTERIES AT YOUR FACILITY?

Nathan Myers
Electrical Engineer

James DeHaan
Electrical Engineer

Bureau of Reclamation
Denver, CO 80225

INTRODUCTION

Emergency backup DC (direct-current) power is of the utmost importance at the Bureau of Reclamation (Reclamation). Reclamation operates 58 hydroelectric power plants located throughout the 17 western United States. Multiple backup power systems are deployed at these power plants and associated facilities to provide emergency power to systems such as powerplant protection, powerplant control, security, communications, emergency lighting, etc. Prior to 2003, all backup DC power systems were comprised of batteries, with some systems also incorporating an engine-generator.

In spring 2003, the Hydroelectric Research and Technical Services Group initiated a research effort to investigate alternative backup power systems. New backup energy technology such as flywheels, ultracapacitors, and fuel cells were explored as a replacement for batteries. Efficiency, initial capital cost, operation and maintenance costs, and environmental impact were some of the criteria used to evaluate these new systems. Of these new technologies, we determined the fuel cell stands out as a very promising alternative backup DC power system which meets Reclamation's needs.

BACKGROUND

Recent storage battery evaluations conducted at Reclamation's Eastern Colorado Area Office indicated several 48-V DC batteries at communication sites need to be replaced. These sites require a low-power (typically less than 1000 W) system to provide power to microwave communication equipment. Power plant personnel indicated that an extended backup time of up to 3 days continuous operation would be desirable for these systems due to the remote location of the sites. Sizing a typical storage battery to provide 72 hours of backup power had many drawbacks, including high cost of batteries, limited space for installation, and high maintenance costs.

ALTERNATE ENERGY SOURCES

Different options were considered and compared to determine which backup power system best meets Reclamation's needs for the communication systems. The options considered included: batteries, ultracapacitors, flywheels, engine generators, and fuel cells. These systems were then compared using initial cost, maintenance, reliability, capacity, and overall life span. As illustrated by table 1, the fuel cell met all these requirements.

The major drawback to storage batteries and engine generator systems is the high maintenance requirements. If periodic maintenance is not performed, the system may not operate at rated capacity, and there is a chance that it may not operate at all. The flywheel and ultracapacitor systems both require very little maintenance; however, their energy storage is limited. These systems were mainly designed to supply energy over a fairly short period of time. One important feature of the fuel cell is the maintenance aspect of the equation. The cost and time required to perform periodic maintenance at remote communication sites is high and can be easily overlooked because of limited access to remote sites. The predicted maintenance costs associated with the fuel cell are greatly reduced when compared to battery maintenance requirements. The fuel cell is also capable of meeting our requirement for extended operation times. Unlike backup batteries, the fuel cell run time is determined by the amount of hydrogen gas available at the site. This time can be extended easily with additional hydrogen cylinders.

Table 1. Comparison Between Different Backup Power Systems

Type of Backup System	Low Cost	Low Maintenance	High Reliability	Long Run Time	Low Pollution	Long Life
Engine Generator	**NO**	**NO**	**YES***	**YES**	**NO**	**YES**
Battery	**YES**	**NO**	**YES***	**NO**	**NO**	**NO****
Flywheel	**NO**	**YES**	**YES**	**NO**	**YES**	**YES**
Ultracapacitor	**YES**	**YES**	**YES**	**NO**	**YES**	**YES**
Fuel Cell	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**

* - Reliability is determined by routine maintenance
** - Assuming valve regulated lead-acid (VRLA) with an average life of 5 - 7 years

FUEL CELL OVERVIEW

Within the past few years, more attention has been focused on fuel cells and their applications as the costs of the fuel cells have decreased and manufacturers have started to focus on the backup power market as a good fit for fuel cells. There are approximately ten different types of fuel cells currently on the market, each with unique operating characteristics. Each type of fuel cell has its own advantages and disadvantages, providing a power solution for many different types of applications. However, the type of fuel cell used for most small-scale applications is the Proton Exchange Membrane (PEM) fuel cell. The advantages which accompany this design include a lower operating temperature of approximately 80 °C, and a relatively high power density. This allows the unit to react to operating conditions faster and to vary power output quickly to meet the demand placed on the unit. Overall efficiency ranges from 35 – 45 percent. Disadvantages associated with this technology include slightly decreased efficiencies due to lower membrane operating temperatures relative to other fuel cells technologies. It should be pointed out that some PEM fuel cells require laboratory grade hydrogen (99.995 percent pure).

After reviewing what was commercially available, we decided to field test a fuel cell manufactured by ReliOn, formerly Avista Labs. The ReliOn I 1000™ [Figure 1] is a fuel cell designed to be used with communication systems. The unit supplies up to 1kW of power at 48-V DC. For loads larger then 1kW, multiple units can be connected in parallel to obtain the needed capacity. The ReliOn I 1000™ was chosen for four main reasons. First, the PEM technology used in this unit offers a higher power density, which decreases the overall size of the unit. The second reason is the modular design. This system consists of six fuel cell cartridges connected in parallel. The N+1 redundancy is provided to increase the reliability of the system. This design also allows any of the six fuel cell cartridges to be replaced, even while the unit is operating. Third, the cost of the unit was about $6,000 which was very competitive compared to other fuel cell manufacturers. Finally, the ReliOn unit also operates on industrial grade hydrogen (99.95 percent pure). Industrial grade hydrogen costs less and is more accessible than laboratory grade hydrogen.

Major Advantages

The most advantageous characteristic of the fuel cell is that it is environmentally friendly. The fuel cell's byproduct is H_2O, and has an overall efficiency of 35 percent or greater. Quite an environmental advantage when compared to engine generators which run at 15-20 percent efficiency and produce greenhouse gases. Another advantage is the fuel cell ability to switch fuel cylinders while the unit is running. This permits extended run times while under load. When a storage battery becomes discharged, the only way to reverse the chemical reaction is to charge the battery. The energy from the fuel cell is derived from a chemical reaction between hydrogen and oxygen. When the hydrogen is valved off, no reaction occurs. Thus, the fuel cell promises to have a long stand-by life (at least 10 years) and requires little maintenance because it is not dependant upon maintaining a constant float charge as with batteries, or moving parts which can wear out as with engine generators.

Concerns

While investigating fuel cell technology, we concluded that the advantages outweigh the disadvantages, but it is still important to take a closer look at these disadvantages. The first concern with fuel cells is the fuel- hydrogen gas. Hydrogen is flammable and must be properly ventilated to reduce the risks of an explosion or asphyxiation. This requires that the fuel and fuel cell be installed outdoors or inside a structure with the appropriate safeguards. These safeguards include gas sensors, ventilation, storing the gas cylinders outside, and for indoor applications, piping in the hydrogen gas via a gas line "fuse." It should be noted that lead-acid batteries also can produce dangerous amounts of hydrogen while charging. Reclamation has taken steps to ensure a safe environment within battery rooms. The same precautions would also apply to a fuel cell installed inside a plant. Given this concern and the lack of space at many communication sites it was decided to install a fuel cell and gas cylinders in an outdoor enclosure.

The next issue which must be addressed is startup time. The fuel cell requires up to 20 minutes to start and ramp to full load. In most cases, the fuel cell can obtain full load much quicker, however, startup time is dependent on the ambient temperature of the unit. When the ambient temperature of the unit is below 4.4 °C, startup can take up to 20 minutes before the unit can supply full load. This lag in startup requires the fuel cell to be used in conjunction with another form of backup power. It was decided to use a small battery as a bridge to carry the load during the startup time to ensure the load is not dropped. The bridge battery is sized to supply the load for 1 hour. To reduce maintenance costs, the annual maintenance on a battery this size would be minimal, and the battery would simply be replaced on a 3- to 5-year replacement plan.

Another downside to the fuel cell is that it is a developing technology. Widespread use of the PEM fuel cell has only blossomed in the last 8 years. Long term reliability and maintenance requirements have not yet been proven. However, extensive effort by the manufacturer has gone into predicting the performance of the system over time. Accelerated extended life testing and component failure analysis has shown a minimum life expectancy of 10 years.

POLE HILL POWER PLANT EXPERIENCE

Funded in part via Reclamation's Science and Technology Program, a research effort to install and evaluate the hydrogen based fuel cell was undertaken. A demonstration/evaluation project was implemented at Pole Hill Powerplant near Loveland, Colorado, at an elevation of nearly 6,000 feet. This was an ideal test site because the battery currently in place to supply the communication system backup power was scheduled for replacement. The site also experiences extreme temperature swings throughout the year (-25 to 40 °C) which will demonstrate the ability of the fuel cell to operate in harsh environments. Further this site is fairly easy to reach, making evaluation throughout the year possible.

The fuel cell is configured as a backup power supply and is powered down and idle the majority of the time. When primary power is interrupted the bridge battery supplies power while the fuel cell is started. Once up to full power, the fuel cell delivers power to the equipment and recharges the battery until the primary power is restored. The measured fuel cell load at this site is about 350 watts. Six hydrogen cylinders, along with the fuel cell, are contained within an outdoor enclosure. The backup run time at this site, given six full hydrogen cylinders, exceeds 72 hours. The unit was installed in October 2003. It was then subjected to extensive testing during the following 3 months. In the course of this testing, it has been cycled about 50 times, for a total run time of about 25 hours with only minor issues needing to be addressed. Many of the problems encountered can be attributed to the learning curve encountered when applying a new technology.

The following site tests have been conducted on the fuel cell to ensure the fuel cell operates as designed. These tests and their results include:

- Short Circuit – A sudden short circuit was placed on the output of the fuel cell. The fuel cell overcurrent breaker cleared the fault. No components were damaged.
- Power Quality – The noise on the DC output from the DC-to-DC converter was measured. With the bridge battery connected, the noise was measured to be 700 mVpp at a very high frequency. With the bridge battery disconnected the measured noise was at 6 Vpp.
- Loss of AC – We verified the fuel cell started with loss of AC to the 48-V DC power supply.
- Low Voltage DC – Our initial fuel cell tests indicated the fuel cell did not start up on low DC bus voltage as stipulated in Reclamation's specification. The manufacturer added an external circuit and updated the firmware to correct this Problem. Subsequent tests verified the fuel cell started on low DC bus voltage.
- Full Load Heat Run – We connected an external load to the fuel cell and ran it at 1kW for 3 hours. No abnormal conditions or temperatures were observed.

- Load Rejection – During sudden change from full load to no load, the output voltage varied from 54.5V (nominal) to 60V. The unit returned to nominal output voltage in 26 seconds. The manufacturer updated firmware to decrease the voltage response time to 5 seconds.
- Cold Start – The unit was started with an outside air temperature of about -6 °C. The fuel cell started, but the internal temperature was below freezing, causing moisture to freeze within the fuel cell. This caused the start time to increase to approximately 50 minutes. A larger heater and additional insulation were installed in the enclosure to ensure the fuel cell will remain operational down to -40 °C outdoors.

These tests have been critical in determining the true capabilities of the fuel cell. They also have helped to identify areas needing improvement for both Reclamation and the manufacturer to address. While the fuel cell has not been without problems, these problems mostly have been related to integrating the fuel cell to meet our specifications. The fuel cell itself and its associated fuel controls have functioned without problems.

We also added a DC watt-hour and runtime meter to monitor the fuel cell performance. This meter makes it possible to monitor the fuel consumption versus the energy produced. Monitoring the efficiency of the unit will also allow Reclamation to detect small hydrogen leaks in the system. This modification will also monitor the run time to determine the total number of hours the unit has been in operation.

Figure 1. Pole Hill Fuel Cell Installation

ECONOMIC EVALUATIONS

The total installation cost for the testing and demonstration of the fuel cell at Pole Hill Powerplant cost Reclamation approximately $46,000. This was broken down to $24,000 in labor and $22,000 in equipment and plant modifications. If we remove testing, demonstration, and one time costs, it is estimated that future installations, including a manufacturer’s 7-year warranty will be $31,000 per unit.

Using the experience and data obtained from this demonstration project, Reclamation predicted the life cycle cost of both storage batteries and fuel cell systems. The economic benefits related to reduced maintenance and testing costs possible over a 10-year period by utilizing a fuel cell over conventional batteries are shown in table 2. Costs are calculated based on a 1-kW load using a 7 percent discount rate and 4 percent inflation.

Battery initial costs shown in the table include the cost and installation of the battery and the cost and installation of a battery monitoring system. The monitoring system precludes monthly and quarterly maintenance. Battery maintenance costs shown in the table include onsite inspection every 6 months and capacity testing every 2 years. The battery is replaced on a 5-year schedule (typical lifespan of Valve-Regulated Lead-Acid (VRLA) batteries used at Reclamation facilities), however the battery is replaced once for this 10-year economic evaluation.

Fuel cell costs include the cost and installation of the fuel cell, an outdoor enclosure, 7-year warranty, and on-site inspections and maintenance performed at 6-month intervals. Cost comparisons were limited to 10 years, although we fully expect the fuel cell to last much longer. The initial fuel cell cost is slightly greater than an equivalent battery, for run times less then 72 hours. However the cost over 10 years will provide a significant savings for run times greater than 8 hours and can be used to justify the use of fuel cell technology.

Table 2. Economic Evaluation of Fuel Cell vs VRLA Battery Over 10-year Period

	Runtime (Hours)	Initial Cost*	Maintenance Costs*	Replacement Costs*	Total Cost*	Fuel Cell Savings (%)
Battery	8	$13,400	$11,900	$5,000	$30,300	(24)
	24	$18,800	$11,900	$9,600	$40,300	6
	48	$29,000	$15,400	$17,500	$61,900	39
	72	$39,200	$17,100	$25,300	$81,600	54
Fuel Cell	72**	$31,700	$5,100	$900	$37,700	

* All costs are shown in present value.

** Additional hydrogen cylinders may be added to the system to extend overall runtime. Twenty-four hours of additional runtime will increase the total cost by about $800.

CONCLUSION

The fuel cell is a viable backup power solution for systems which require long backup times at low power consumption. Cost comparisons, maintenance requirements, environmental issues, and expected life all favor the use of fuel cells for backup power. Safe work practices involving the use of hydrogen must be observed when designing and maintaining the system.

Presently, we would not recommend the use of a fuel cell for primary or vital systems such as powerplant control and protection power. Only flooded lead-acid batteries are recommended for these applications because of their proven track record of performance. For less critical systems such as Reclamation’s communication and monitoring systems, other backup systems are a viable option. At these sites, the fuel cell should be considered a prime candidate to provide backup power.