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Fuel Cells in Backup Power Applications

Clean power generators – an alternative to conventional backup power sources

Introduction

Availability and reliability of backup power sources are a major concern in the United States. Weather conditions and a fragile power infrastructure have caused blackouts across the country, making customers and service providers look for backup power solutions that offer durability and flexibility, at a reasonable cost. More recently, the realization that our power generation and distribution system may be vulnerable to interruptions increased this need significantly.

There are a variety of backup electrical power systems that all strive to provide power when the grid power is unavailable; yet how each system achieves this goal is very different. For many years, backup power has been provided primarily by valve-regulated lead-acid (VRLA) battery systems (i.e., UPS systems) and engine-generator sets. More recently, ultra capacitors, flywheels and new battery technologies have been employed. Although each technology has some advantages; the disadvantages are significant enough that service providers, especially those employing outdoor applications, are searching for alternatives. Fuel cell manufacturers have responded by designing fuel cell systems to compete with traditional technologies meeting backup power requirements in stationary applications.

Alternatives

At a minimum, the backup power system for any application must be able to supply the required power to the critical loads for the desired length of time. Subsequently, the advantages and disadvantages of each system must be considered. The ideal solution is the system which meets all the needs for a given application, though in reality, a combination of systems may be the solution. One of the main determining factors on what system to use is the range of power required. In this paper we are only addressing applications that require less than 5 kilowatts (kW).

In this power range, batteries and engine-generator sets are the conventional technologies that are used for backup power applications. Each has advantages and disadvantages associated with them. VRLA battery systems are low cost and generally considered reliable. However, VLRA battery systems are transitory, typically designed to provide power (defined by a finite stored amount) for approximately 15 minutes at full power, enough time to complete an orderly shutdown of equipment. In addition, the systems are heavy and overly sensitive to temperature. Engine-generator sets, with proper maintenance, can be very reliable; yet they produce combustion emissions, require fuel storage, and are noisy and high maintenance items—the latter of which can be a major problem if the location is remote.

These conventional technologies have a variety of competition including advanced battery technologies, flywheels, and ultra-capacitors. Although these alternatives may have some merit, the intention of this paper is to review the technology and applications of only one alternative to these conventional technologies, the proton-exchange-membrane (PEM) fuel cell system.

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Hydrogen-fueled PEM Fuel Cell

A typical backup power fuel cell system includes the following components:

- fuel cell (the power generation section),
- the auxiliary components often called the balance of plant (i.e., power conditioner, controls, fans, etc.), and
- hydrogen fuel storage and delivery source.

The technology has evolved beginning with the fuel cell, followed by controls, and finally integration of the auxiliary equipment into a viable system. Thus, the main component of the technology, the fuel cell, is the most developed of all the components of the system. Moreover, the fuel cell power generation section has no moving parts, which is the main reason that fuel cell systems are expected to require little or no maintenance.

The technology uses an electrochemical process rather than a combustion process to produce electric energy (direct current electricity) that generates zero emissions and little noise. This technology operates at low temperatures, approximately 80°C (176°F), which allows for quick start-up time to provide immediate and, as necessary, extended response to power interruptions. Fuel cell systems are modular units that are scalable to meet the needs across a wide power range. In addition, the systems have relatively high power density, low weight, and a small footprint.

However, there are complications associated with the use of fuel cell technology. PEM fuel cell systems require hydrogen for fuel (either a high purity grade hydrogen or a standard industrial grade hydrogen), which has some users concerned about safety associated with the use and storage of hydrogen.[1] However, the National Fire Protection Association (NFPA) 853 (NFPA, 2003) and NFPA 55 (NFPA, 2005) codes provide guidance for installation of stationary fuel cell power systems and safe storage, use and handling of compressed gases, respectively. Another consideration is the logistics of providing a continual supply of hydrogen cylinders for the fuel cell system. As fuel cell systems are deployed more extensively, the question of whether or not these issues can be mitigated or overcome will be determined.

Hydrogen-fueled PEM Fuel Cell Applications

There are many PEM fuel cell manufacturers at varying stages of development and commercialization of their products. At least five of these manufacturers appear to be targeting the backup power markets. Recently, some of these manufacturers have tested their products in field applications, yet; few are testing in the federal sector, which is the focus of this review.

Fuel cells can be configured to provide power completely independent of the grid, use the grid as backup power or provide backup power to a grid-connected system should the grid fail. The latter is the typical configuration for backup power.

Several federal sites are involved with testing the ability of PEM fuel cell systems to keep critical loads operational during power outages. Primarily, the applications are stationary and often the sites already employ a backup power technology that they are considering replacing or supplementing the existing backup power source with another technology to extend the periods of runtime. For example, the fuel cell can complement a battery. In the configuration as the fuel cell ramps up to full power, the batteries supply the power, and then when the fuel cell is operating at full power, the fuel cell takes over the load and recharges the batteries. The system still requires batteries or a similar technology to cover lapses during start-up or even to cover peak conditions, but the capacity of batteries needed is greatly reduced.

McChord Air Force Base

In 2003, a 3-kW system (consisting of six smaller 500-W modular fuel cells) was installed at McChord Air Force Base (AFB) in Tacoma, Washington (see Figure 1). This 1-year demonstration project (through April 2004) was sponsored by Construction Engineering Research Lab (CERL), a

Figure 1. Fuel cell model installed.*

** This is the model installed and tested; however, at the end of test the site was upgraded with the latest product design and converted to a permanent installation.*

1 The cost of industrial-grade hydrogen fuel can range from $20 to $30 per cylinder, which can fuel the generation of roughly 8 kilowatt-hours. While hydrogen is an expensive fuel source for stationary power systems, for backup power systems the cost of fuel can be negligible compared to the initial equipment costs and recurring maintenance costs provided annual run time does not become prolonged.

division of the U.S. Army Engineer Research and Development Center (ERDC). In this demonstration, the fuel cell system responded to a loss in power and supplied backup power to a load bank located at a radio transmit receive (RTR) equipment site owned and operated by the Federal Aviation Administration (FAA).

The 12-month demonstration was a two-phase test. During the first phase the fuel cell responded to a 20-minute loss of AC power three times each day for seven days a week. This phase lasted for 6 months. The second phase, another 6-month period, added a 2-hour grid power failure every Sunday to the daily tests. During the simulated grid failure, the fuel cell system carried the entire RTR load, while maintaining charge voltage to the facility battery system for the 2-hour period.

Over the demonstration period, the system was monitored over 8800 hours, and accumulated over 1100 successful starts, for a total system run time of 419 hours. Total reliability (actual starts/attempted starts) was 99.4% and total availability (actual run time in scheduled period/scheduled run time in period) was 97.4% (Binder et al., 2004; ReliOn, 2004).

The use of fuel cells as a backup power supply was successfully demonstrated by CERL at McChord AFB (Binder et al. 2004). According to the ERDC-CERL report, availability and reliability of less than 100% was attributed to issues associated with the "sub-components." The issues that were listed included:

- overly sensitive hydrogen sensors causing system shutdown
- inappropriate gas connections that led to loss of fuel supply
- shorting of pad heaters which resulted in the system failing to start.

These issues were remedied by installing new sensors, ensuring proper connections and delivery of fuels and replacement of redesigned pad heaters. Further, the ERDC-CERL report concluded that although the PEM fuel cells alone have not achieved greater reliability than conventional backup power, the project demonstrated their potential when paired with a battery array (Binder et al. 2004).

Bureau of Reclamation

The Bureau of Reclamation (BOR) operates 58 hydroelectric power plants and has multiple backup power systems deployed at these plants to provide emergency power to systems such as plant protection, controls, security, communications, and lighting. In 2003, the Hydroelectric Research and Technical Services Group within the BOR investigated backup power sources for use at BOR plants. Some of the backup power sources considered for use included batteries, ultra-capacitors, flywheels, generators and fuel cells.

The BOR evaluated these backup power options (see Table 1) and determined by comparison that fuel cell technology was the best choice for one of their sites in Colorado (Myers and DeHaan, 2005). Prior to this evaluation, all the DC backup power needs at the BOR have been met by battery and/or engine-generators.

A fuel cell system was installed at the Pole Hill Power Plant near Loveland, Colorado (see Figure 2) to replace an existing battery bank of 48 V-DC batteries at this communication site. This site was chosen because the existing battery bank was scheduled for replacement. Although this site is somewhat remote, located at an elevation of nearly 6,000 feet, it was considered accessible, so evaluations could be made throughout the year. In addition, the site has extreme temperature ranges during the year, (-25ºC to 40 ºC), which would demonstrate the fuel cell system's ability to operate in harsh environments.

Table 1. BOR comparison between different backup power systems.

Types of Backup System	Low Cost	Low Maintenance	High Reliability	Long Run Time	Low Pollution	Long Life
Engine Generator	No	No	Yes*	Yes	No	Yes
VLRA 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.

***Hydrogen-based PEM fuel cell.

Figure 2. BOR fuel cell application site.

The site required low-power (<1000 W) of 48 V-DC for microwave communications equipment. It was specified that the system should be able to provide extended backup power for up to 3 days of continuous operation.

The system included a modular, hot-swappable cartridge-based fuel cell[2] (see Figure 3), controls, and an outdoor enclosure. The enclosure is optional, but typically is included to facilitate maintaining the internal temperatures above freezing to enable rapid startup of the unit. The system was fueled by industrial grade hydrogen gas (provided in a lockable storage container), which was supplied by compressed gas with a dedicated delivery system for security and safety (see Figure 4).

Although PEM fuel cells have relatively quick start-up times compared to other fuel cell types, in cold climates (<4.4°C) the fuel cell system can require up to 20 minutes to start up and reach full load. Thus, PEM fuel cells typically require another backup power source, such as ultra-capacitors or a (bridge) battery bank, the latter of which was

Figure 3. BOR fuel cell power generation cartridges.

Figure 4. BOR fuel cell model installed.

2 Cartridges house the fuel cell power generation section of the fuel cell system.

3 The Building Life-Cycle Cost computer program BLCC5 was developed by the National Institute of Standards and Technology (NIST) under the sponsorship of the Federal Energy Management Program of the U.S. Department of Energy (DOE/FEMP).

the source chosen for this demonstration. The bridge battery bank was expected to be replaced every 5 years.

Maintenance consisted of routine visual inspections by authorized personnel, and occasionally the system needed equipment adjustments. In addition, a remote monitoring system can be installed to indicate that a PEM modular cartridge has failed, and the unique design enables the system to keep operating while the cartridge is taken off-line and/or replaced.

The BOR engineers completed an economic analysis based on their experience and test data, which exhibited an economic savings associated with using fuel cell technology over batteries alone. Using this same data provided by the BOR, a life cycle cost analysis was performed using Building Life-Cycle Cost (BLCC)[3] and the results were favorable toward fuel cell technology compared to the VLRA battery technology (see Table 2).

The actual list price for the 1-kW PEM fuel cell is $6,750. The $31,000 listed in Table 2 represents a turn-key project and includes the following costs:

- fuel cell
- fuel cell enclosure
- shipping, insurance and warranty
- installation and connections
- site commissioning and training
- bridge battery installation and disposal costs
- hydrogen cylinders and fuel for 48-kWh capacity.

The actual list price for the VLRA batteries is $16,200. The $29,000 listed in Table 2 represents a turn-key project and includes the following costs:

- battery for 48-kWh capacity
- battery racks
- monitor
- monitor installation
- battery disposal costs.

The BOR deemed the fuel cell a viable backup power solution for systems requiring long backup times at low power consumption. However, the BOR concluded that presently it would not recommend the use of fuel cells for primary or vital systems, such as power plant control and protection power until a proven track record of performance is established. Rather, the BOR would consider the use of fuel cells for less critical systems, such as communications and monitoring systems (Myers and DeHaan, 2005). The BOR is considering additional sites for future PEM fuel cell applications and is planning to monitor the existing fuel cell system for 5 years, with completion of the project expected in fiscal year 2008.

Conclusions

There are approximately five fuel cell manufacturers targeting their fuel cell technology systems for the backup power market. However, each is at a different stage of development. A few are commercially available and have participated in various field tests. To date, there has been only one manufacturer that has completed demonstrations of its backup power PEM fuel cell system in the federal sector with data to report. The field testing has enhanced the technology, improving the stability and durability over the years. It has also shown that in certain applications, the technology can cost-effectively address reliability issues.

Further, to ensure early adopters that fuel cells are robust and can meet their needs, pioneering fuel-cell manufacturers are beginning to design systems that comply with recognized standards and certifications. Some systems have been UL-certified to ANSI Z21.83, a U.S. national product standard for fuel cells, and the telecommunications industry standard called the Network Equipment Building Standards (NEBS). Approval of the latter standard, NEBS, indicates that a product has passed a series of tests ensuring that the product will operate properly in harsh environments and will not cause harm to the environment or personnel (Arc Electronics, 2005).

To facilitate procurement of fuel cell systems, several PEM fuel cell backup power systems have been listed in the General Services Administration (GSA) Schedules. For more information visit the GSA Advantage website at https://www.gsaadvantage.gov.

For additional information on this technology, the identification of major fuel cell manufacturers and the emerging applications for this technology visit the U.S. Fuel Cell Council's website at http://www.usfcc.com.

Table 2. Comparison between backup power systems for 48-hour capacity.

Backup Power System	Initial System Cost	Maintenance Costs	Battery Replacement Costs[b]	PV Life Cycle Cost[c]
VLRA Battery	$29,000	$600/yr + $3,000/2 yrs[a]	$20,260	$53,250
PEM Fuel Cell	$31,000	$600	$1,100	$36,457

[a] Performed capacity test every other year.

[b] 5-year life expectancy for VLRA batteries.

[c] Based on 10-year life expectancy and using NIST BLCC 5.3.

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