DE-EE0000487 Final Technical Report

Recovery Act - PEM Fuel Cell Systems Providing Emergency Reserve and Backup Power

Director/Principal Investigator: Mike J. Maxwell, P.E.

Award Recipient: ReliOn, Inc.

Teaming Members: AT&T, PG&E, and Air Products and Chemicals, Inc. (APCI)

Executive Summary

The goal of this project was to install and operate hydrogen fuel cells as back-up power equipment for nine communications sites in use by Pacific Gas & Electric (PG&E), a California utility, and as critical emergency reserve power for 180 cell sites operated by AT&T. The objectives of the project were to demonstrate that fuel cells are a reliable source of clean back-up power for key communications facilities, and to help transform the market within PG&E and AT&T by moving beyond limited demonstration sites to wider deployments, thereby generating a higher level of awareness within PG&E and AT&T regarding the benefits of fuel cells as a back-up solution, and having been proven as such over this project, encourage additional future deployments. By stimulating wider deployments within two networks across 10 states, the project did indeed foster higher visibility within PG&E and AT&T, as well as the industry in general. This in turn helped to build a critical mass for advanced refueling infrastructure using compressed hydrogen, provided broad experience to site acquisition vendors and installation contractors, and helped to educate and familiarize the technology to authorities having jurisdiction (AHJ's).

Accomplishments vs. Goals and Objectives

The stated goals and objectives for this project are as follows:

- Install fuel cell cabinets (431 fuel cell systems total) with 72-hour capacity as back-up power equipment for nine communications sites in use by Pacific Gas & Electric (PG&E), a California utility, and as critical emergency reserve power for 180 cell sites operated by AT&T.
- Demonstrate that fuel cells are a reliable source of clean back-up power for key communications facilities.
- Transform the market within PG&E and AT&T by moving beyond limited demonstration sites to wider deployments.

Goal/Objective: “Install fuel cell cabinets (431 fuel cell systems total) with 72-hour capacity as back-up power equipment for nine communications sites in use by Pacific Gas & Electric (PG&E), a California utility, and as critical emergency reserve power for 180 cell sites operated by AT&T.”

Accomplishment of Goal/Objective:

All nine of nine sites were constructed within PG&E per plan. The systems provide over 72 hours of backup runtime capability for PG&E’s supervisory command and data acquisition (SCADA) remote monitoring and control platform. As of the EOQ2-2012, 170 of the 180 AT&T sites were constructed, commissioned, and handed off to AT&T. This totals 392 fuel cell systems deployed for AT&T through EOQ2-2012. Of the remaining 10 sites (30 fuel cell systems), seven are presently under construction and three are pending the release to construction. These 10 sites (30 systems) are expected to be construction complete and handed off to AT&T within 60 days, thus completing the project and fulfilling ReliOn’s commitment.

Goal/Objective: “Demonstrate that fuel cells are a reliable source of clean back-up power for key communications facilities.”

Accomplishment of Goal/Objective:

The 179 sites at PG&E and AT&T equipped with ReliOn fuel cells provided through this project are functioning well. All sites operated per design and carried the site loads properly when commissioned. Though many of the sites have yet to report an actual power outage, there have been no reports of missed outages. Performance data from 15 sites was collected and reported to the National Renewable Energy Laboratory (NREL) through EOY-2011 as required. The automatic periodic exercise feature built into the ReliOn fuel cell insures that the systems are ready to cover a site outage, which insures that the connected communications systems are now more robust than prior to the execution of this project. The bulk refueling model is working well and APCI has discussed the possibility of building more straight truck refueling vehicles to add to their current fleet. All responsible PG&E and AT&T field technicians have been trained in multiple markets so that they are prepared to care for the equipment under their control as needed. Both PG&E and AT&T have commented that they appreciate how the fuel cell is a zero-emissions device exempt from air quality permitting and reporting. They also appreciate the minimal maintenance involved in comparison to legacy, competing generator technologies fueled by propane or diesel.

Goal/Objective: “Transform the market within PG&E and AT&T by moving beyond limited demonstration sites to wider deployments.”

Accomplishment of Goal/Objective:

As a result of this program, PG&E has recently ordered five more sets of equipment and has asked ReliOn to provide the installation services as well. AT&T is presently in discussion with ReliOn regarding a possible follow on program consisting of multiple hundreds of sites which would utilize the newest E-series fuel cell from ReliOn which offers >2X the power density of the T-series fuel cells deployed through this program. The new deployments would also utilize the hydrogen storage module (HSM) developed through this project which would be filled in place by a bulk fueling vehicle.

Project Activity Summary; August 1, 2009 - December 31, 2011

Introduction

Market transformation is best achieved by reaching a critical mass in the market that significantly raises awareness and direct experience of the value proposition. With the assistance of this project, ReliOn is installing 431 fuel cell systems (within 189 cabinets) into the telecommunications and utility networks at AT&T and PG&E for backup power, across ten states, combined with the deployment of a refillable stationary hydrogen storage module (HSM) unit and the accompanying refueling logistics platform for 180 AT&T sites. These are real-world, tangible changes to the market resulting in the use of hydrogen based systems to harden critical communications networks.

Background

ReliOn's fuel cell systems are self-contained, backup power generators which use proton exchange membrane fuel cell technology. These systems incorporate an onboard gaseous hydrogen fuel supply which consists of replaceable industrial gas cylinders and/or a refillable stationary hydrogen storage module. These are hardened, proven, commercial products which ReliOn has been providing to its end-users since 2003 and ReliOn fuel cell systems are deployed within 42 US States and 34 countries to date. Shown below in Figure 1 is an example of a standard 4kW outdoor cabinet solution with 6 replaceable hydrogen cylinders contained within the hydrogen storage cabinet. The equipment cabinet on the left contains 2 ea. T-2000® 2kW fuel cell chassis each equipped with 10 modular PEM cartridges.

FIGURE 1. T-2000® 4kW outdoor enclosure fuel cell system

While there are a number of fuel cell technologies available, the most common and practical technology for standby power is the proton exchange membrane, or PEM, fuel cell. The only inputs to the fuel cell are industrial grade hydrogen (99.95%) and oxygen (air), with the only byproducts being pure water/vapor and heat. As a result, fuel cells are considered a green technology, making them an attractive solution for installations with emissions restrictions. PEM fuel cells do not burn their fuel to create electricity as is the case with most other generators, rather they operate electrochemically like a battery and combine the hydrogen and the oxygen across a solid electrolyte (PEM) which generates the electrical power output. A high-level representation of the PEM fuel cell process is shown below in Figure 2.

FIGURE 2. The PEM fuel cell process

One of the other attributes of a fuel cell that makes it attractive for deployment in many applications is that a fuel cell produces DC power. This makes a fuel cell akin to a standby rectifier source, as the power provided from the fuel cell can be directly connected to the site's DC power bus. In an outage situation, the fuel cell turns on automatically, providing DC power, which was formerly provided by the rectifiers. DC output also makes the fuel cell ideally suited for hybrid applications with solar (photovoltaic), wind and battery systems. The fuel cell is akin to a generator, in that the fuel cell is sized for the power requirement, and can run indefinitely provided it has a source of fuel. This means fuel cells, when coupled with an appropriately sized fuel storage solution, can function effectively for long reserve times as a standby power source in customer applications.

The specific telecommunications sites where these ReliOn fuel cell systems were deployed via this program typically had only 1-2 hours of battery backup prior to this fuel cell deployment. These sites have now been hardened with ≥ 72 hours of backup runtime capability.

The ReliOn fuel cell system is designed to be a backup power solution for small DC power applications within the transportation, security, wire-line and wire-less telecommunications, utility, and government sectors. The ReliOn fuel cell system is intended to augment traditional DC power systems. A simplified DC connection diagram is shown in Figure 3.

Typical Site Back-Up Power System: Traditional

Typical Site Back-Up Power System – Fuel Cell

FIGURE 3. Traditional versus fuel cell-enhanced backup power system

Approach

ReliOn's approach to this turnkey deployment program began with the basic research needed to identify viable candidate sites and then narrow down the list in order to focus efforts on the most viable and critical sites that could be installed and refueled successfully, ensuring that these assets will remain viable for decades. This work was primarily performed by ReliOn personnel. For the PG&E portion of the project, ReliOn reviewed database records, site drawings/photos, aerial details, and performed physical site surveys in the field for 19 candidate sites and then down-selected to identify 10 viable sites, with one of these sites slated as a reserve for contingencies. For the AT&T portion of the project, ReliOn reviewed database records, site drawings/photos, and aerial details of 742 candidate sites and down-selected to 258 viable sites, with 78 of these sites comprising the reserve site pool. Physical site surveys were performed in the field for the 258 sites. The next task was to secure rights to perform the construction through the use of site acquisition (SAC) vendors who structure the leasing and permitting packages to prepare the sites for construction. ReliOn utilized third parties who are skilled in this profession and remained part of the program until all SAC activities had been completed.

As a site cleared the SAC process, it was then constructed (typically within one month), fueled with hydrogen gas, and brought on-line as a fully functional backup power system. Installation construction was performed only after the SAC vendor had secured the installation and operating rights for each site. ReliOn utilized third parties to perform installation construction, yet retained the roles of project management and supervision. ReliOn partnered with an established hydrogen provider, Air Products and Chemicals, Inc. (APCI) an industry expert in hydrogen storage and delivery for the development and production of the innovative, stationary, bulk-hydrogen storage module (HSM). Once the sites were installed, fueled and operational, a sample of 15 sites representative of the deployment were monitored remotely for data collection. ReliOn personnel collected and reported fuel cell operational data to the DOE/National Renewable Energy Laboratory (NREL). The use of both ReliOn and third party resources maximized the effectiveness of the project, created or retained jobs across a breadth of companies and regions, and delivered the maximum amount of infrastructure for the given financial investment.

Results

To date, ReliOn has completed the site qualification and the SAC activities on all target sites. During the course of the project, 76 AT&T candidate sites and one PG&E candidate site were cancelled for various reasons (primarily leasing/landlord/zoning issues) and were successfully replaced. ReliOn has installed 401 fuel cell systems at 179 sites to date (392 systems at 170 sites for AT&T and nine systems at nine sites for PG&E) with seven more AT&T sites (21 systems) presently in the construction phase and three more sites (nine systems) pending construction. ReliOn expects to have these remaining sites completed within the next 60 calendar days. This ongoing process of SAC approval and site construction has resulted in the continuous need for labor and has secured multiple jobs.

Two important hydrogen fueling infrastructure technologies were developed as a result of this project. These include the HSM and the single axle 'straight truck'. The HSM was a joint collaboration between project partners ReliOn and APCI. The straight truck fueling vehicle was developed solely by APCI when it was recognized that a more versatile fueling vehicle was needed to open up markets based upon sites which were previously unserviceable by the larger, legacy fueling vehicles. The HSM and bulk refueling are integral product offerings for applications previously un-served due to limitations of cylinder-exchange. Reduced operational cost of delivered hydrogen and longer run-time are accomplished by implementing bulk refueling in place of packaged gas exchange as well.

FIGURE 4. Completed AT&T site in MI market being fueled by a ‘Straight Truck’

Figure 4 above shows an AT&T site located in Michigan which has just completed the initial fill of the HSM during the commissioning process. The fill was performed using the newly developed single-axle straight truck fueling vehicle. This vehicle makes the fueling of certain remote sites feasible and more efficient due to its reduced size, improved mobility, and higher service pressure in comparison to legacy tube trailers pulled by semi-tractors.

FIGURE 5. Fueling of HSM at completed AT&T ‘Poison Springs’ site in Byers, CO

Figure 5 shows a close up of the AT&T ‘Poison Springs’ site located in Byers, Colorado undergoing the initial fill of the HSM during the commissioning process. The leftmost cabinet is the fuel cell equipment enclosure with an adjacent 6-cylinder hydrogen storage cabinet. The larger cabinet to the right with the doors open and red cylinders in view is the HSM. The HSM is connected to the system in parallel with the 6-cylinder hydrogen storage cabinet, and contains the majority of the fuel capacity.

A portion of the fuel cell systems deployed through this program were outfit with cellular modems and communications cards in order to support remote telemetry. The AT&T Poison Springs site in Byers, Colorado was one such site, as was the neighboring AT&T ‘Pena’ site in Denver, Colorado shown below in Figure 6. These sites also have the distinction of being the first two sites constructed for AT&T under this program. Both sites were completed in early February, 2010 and have been on line since that time. The Poison Springs site is an AT&T shelter site which is backed up by a ReliOn 4kW cabinet containing 2 ea. 24V T-2000 fuel cell chassis, and the Pena site is also an AT&T shelter site which is backed up by a ReliOn 6kW cabinet containing 3 ea. 24V T-2000 fuel cell chassis.

As proof of performance, the remote telemetry for the Pena site was recently invoked to extract fuel cell operational/event logs which revealed that since inception the fuel cell system at this site has covered 5 distinct utility power outages ranging from as short as 20 minutes, to as long as 13 hours. Total utility power outages for this site since February, 2010 total just over 17 hours. In the same fashion, the operational/event logs at the AT&T Poison Springs site were recently extracted and reviewed to evaluate system performance. The Poison Springs site has experienced 6 distinct utility power outages over the same timeframe as the Pena site, and one utility outage lasted 73 continuous hours. The ReliOn fuel cell system successfully backed up the site for the entire 73 hour outage and consumed just over 1/3 of the fuel stored within the fuel supply system at the site during this extended outage. In essence, this site can operate in the backup mode for approximately 200 hours during emergency conditions.

FIGURE 6. Fuel cell cabinet and HSM at completed AT&T ‘Pena’ site in Denver, CO

There are currently more than 1,300 telecommunication sites using fuel cell power solutions in North America alone. While this represents a small percentage as far as total telecom sites, it is clear that fuel cells are a growing solution to the need for reliable energy for sites in locations as diverse as cities, suburbs, rural, off-grid and environmentally sensitive areas. The options for backup power are varied, but the most often used power source for moderate-sized telecom sites needing extended runtime is a diesel internal combustion generator. This incumbent technology has been the mainstay for years, despite issues with reliability, maintenance costs and environmental cleanliness. As the nation has shifted its focus to the importance of all these issues, fuel cells have become a viable option for more and more locations.

Telecom operators are very familiar with the use of diesel generators to provide backup power at their sites and are growing in their familiarity with fuel cells. In order to have a meaningful comparison of the two options, it is important to address costs, reliability and environmental factors. In addition to being a familiar technology for telecom operators, diesel generators have historically been a lower initial cost power option when compared to fuel cells. As fuel cell technology has advanced and costs have declined, with further end-user cost reductions spurred by federal and state government grants and tax credits, fuel cells are becoming on par with generators in terms of first cost. On a lifecycle model, fuel cells offer a reduced operational cost when compared to combustion generators.

Item	Typical Fuel Cell: 10kW system in enclosure with fuel storage	Diesel Generator: 50kW with ATS and fuel storage
Capital Cost		
Equipment Cost	\$35,800	\$28,500
Permitting/Installation/Fuel	\$26,000	\$26,000
Federal Tax Credit*	\$18,540	0
Incentives: States**	varies	0
Total Turnkey First Cost	\$43,260	\$54,500
Operational Costs		
Annual Maintenance & Fuel (includes 2 genset rebuilds @ 5yrs)	\$700	\$5000
Lifecycle cost after 10 years	\$50,260	\$104,500
Cost comparison after 5 years	\$46,760	\$79,500
Cost comparison after 1 year	\$43,960	\$59,500
* Federal tax credit is \$3/W or 30% of total capital cost of fuel cell installation, whichever is less. ** State tax credits for fuel cells vary where available. California and New Jersey currently offer the best incentives.		

Operating Costs: Diesel

The cost of diesel fuel fluctuates, but has risen significantly over time from under \$1.50/gallon in 2003 to \$4.06/gallon in May of 2011, according to the U.S. Energy Information Administration's (EIA) record keeping. From 2009 to 2011, diesel prices have risen 57.5%. While wholesale diesel prices may be somewhat less, the trend is still significant as shown in Figure 7 below.

FIGURE 7. Retail diesel prices 2003 – 2011 actual, with 2012 projected

Operating Costs: Hydrogen

As with diesel, hydrogen prices have risen over time as shown in Figure 8. They are not tracked through the EIA; however, a survey of bulk hydrogen prices per cubic foot offers a perspective on cost trends. From 2009 to 2011, hydrogen prices have increased about 29.6%. Recent surveys of bulk gas providers indicate a significant downward trend projected for 2012 due to lower natural gas market pricing and the relative impact on high-temperature steam reforming of hydrogen production on a large scale.

FIGURE 8. Hydrogen prices 2003 – 2011 actual, with 2012 projected

Maintenance Costs: Diesel Generator

Generator maintenance consists of a quarterly service call comprised of seven separate system checklists:

- Cooling System
- DC Electrical System
- AC Electrical System
- Air Induction & Exhaust System
- Power Unit
- Lubrication System
- Fuel System

These quarterly maintenance cycles cost the customer an average \$5,000 annually.

Maintenance Costs: Fuel Cell

A fuel cell maintenance call happens once a year and involves inspection of and possible exchange of a standard air filter. This decrease in maintenance is attributable to the simplicity of fuel cell design and the fact that they have very few moving components. Fuel cell maintenance, including fuel, costs the customer approximately \$700 annually.

Fueling Options

Intrinsic to both fuel cells and diesel generators is the need for fuel in order to operate. Diesel is widely available through a fueling network of “bump trucks”, which arrive at outside plant sites as needed to refuel a large storage tank onsite. Historically, fuel cells have used exchanged hydrogen cylinders to store fuel (referred to in the industry as “packaged gas”). Refueling sites outfitted with packaged gas is accomplished by the exchanging full cylinders for empty cylinders at the site.

A second option for fuel cells is bulk hydrogen refueling. ReliOn has worked with existing bulk hydrogen suppliers to establish a refueling model similar to the diesel/propane model. In this model, the cylinders remain on site and the fuel is transported by a fuel truck (bulk refueler). The cylinders are filled on site by the refueler by re-pressurizing the tanks. This development has broadened the market for fuel cells to address higher capacity installations and sites requiring extended run times of several days.

The development of a bulk refueling option places hydrogen fuel cells on a level playing field with diesel generators when comparing costs related to the fueling process. Just as with other infrastructure fuels, when assessing the suitability of a site to use this bulk refueling model, it is important to address potential issues such as sufficient site access, turning radius, and road conditions that support the weight of the trucks.

Reliability

The reason power engineers add backup power to the site design is to increase the reliability of the site, so that the company can continue to provide service to its customers despite events that knock primary power out of service. Thus, the reliability of the backup power equipment is paramount to the goals of the operator.

Diesel generators of the size routinely used at telecommunication outside plant sites have a reliability rating of 88.4% (*1). ReliOn fuel cells have a reliability rating of 99.63%. This was arrived at through third party testing in commercial customer environments over the course of three years.

Environmental Issues

-Noise

Sensitivity to noise is dependent on the location of the site needing backup power. Sites located in neighborhoods or locations where people congregate will have a lower threshold than remote sites. Diesel generators and fuel cells both have ranges of noise, depending on the product selected and its configuration. A survey of diesel generator and fuel cell specs shows that the average fuel cell is about 10 decibels lower than the average generator.

-Toxicity

Fuel toxicity has the potential to add costly cleanup in case of fuel spills. Diesel fuel, being heavier than air, spills directly onto the ground and can lead to significant contamination of the soil if not dealt with promptly. Soil must be excavated and surrounding areas tested for acceptable levels of contaminants. More extensive measures must be taken if contamination reaches ground water and public water supplies. Hydrogen does not have these issues. Hydrogen is non-toxic and because it is much lighter than air (1/14th the density of air), it disperses quickly if leaked.

-Exhaust

Diesel generators are notorious for their pollutants. States such as California have set limits to the number of hours a generator can be run in non-emergency situations in order to address the emissions issue (*1). Federal guidelines limit the amount of emissions allowed by generators (*2). The 50kW diesel generator in our example falls under Tier 2 standards and is allowed 5 grams of carbon monoxide (CO) per kilowatt-hour, 7.5 grams of NO_x per kilowatt-hour and 0.4 grams of particulate matter per kilowatt-hour. When one extrapolates to 1,000 generators providing 150 hours of runtime per year each for 5 years, the environmental impact, as shown in Figure 9, becomes very clear.

(*1) http://www.dieselserviceandsupply.com/generator_engine_emissions_explained.aspx

(*2) <http://www.dieselnet.com/standards/us/nonroad.php#tier3>

Assumptions:
1,000 sites
50kW diesel generator / 10kW fuel cell
150 hours runtime per year
5 years

FIGURE 9. Environmental impact based upon grams of CO, NOx, and particulate matter emitted

Comparatively, fuel cells running on hydrogen emit no pollutants. This makes them an ideal solution for locations where air quality is an issue. Hydrogen fuel cell emissions are comprised entirely of a small amount of heat and a little water.

As an alternate hydrogen fuel source option for purposes of comparison, a fuel cell operating on reformed methanol also has significantly lower emissions than the diesel generator, with 0.007 g/kWh of NOx, 0.17 g/kWh of CO and 0 g/kWh of particulate matter.

When comparing the carbon dioxide (CO₂) emissions of diesel generators and hydrogen fuel cells, the further disparity between the solutions is evident as shown in Figures 10 and 11. While the diesel generator emits 1,500 grams of CO₂ per kilowatt hour, the fuel cell running on hydrogen has no emissions at the point of use. Conversely, fuel cells running on reformed methanol emit 783 grams of CO₂ per kilowatt hour; roughly half what the diesel generator emits. While the fuel cell using reformed methanol is certainly cleaner than a diesel generator, it is clear that the hydrogen-fueled fuel cell remains the cleanest option.

FIGURE 10. Comparison of CO₂ emissions from H₂ and MEOH fuel cell systems and diesel generators

For fuel cells using reformed methanol as a source of hydrogen, Figure 11 below shows the sum total of carbon emissions from production of the fuel source, to final production of electrical power in the field.

FIGURE 11. Comparison of total CO₂ emissions from MEOH fuel cell systems and diesel generators

Conclusions

While it is true that diesel generators have a much longer history of use at telecommunication sites than do fuel cells, based on costs, reliability data and environmental factors, it is evident that fuel cells are now capable of providing highly reliable backup power at a cost that saves the telecommunications provider money while helping to address sustainability objectives.

The project brought together a leading fuel cell system manufacturer (ReliOn) with the nation's largest wireless telecommunications carrier (AT&T), a predominant California utility (PG&E), and a major industrial gas supplier (Air Products and Chemicals, Inc.), to field commercial systems in real-world installations across a broad range of environments. The critical mass of systems enabled the program team to penetrate nation-wide regions with corporate level attention, and catalyze non-DOE-funded activities in fuel storage and delivery. During the course of this project, ReliOn learned that the dropout rate of sites undergoing SAC was higher than expected which resulted in delays causing the deployment to extend beyond the contract end date of December 2011. ReliOn expects to have all work completed within the next 60 days. This project deploys fuel cell systems within ten states, though it promotes jobs and supports business in other states which are the home bases of various subcontractors.

Conference Papers

FY 2010 Publications/Presentations

1. Cohen, M.S., Kenny, K.P., "Hydrogen Delivery and Storage Options for Backup Power and Off-Grid Primary Power Fuel Cell Systems: Two Years Later", IEEE INTELEC Conference, Orlando, FL, June 9, 2010. (Paper and Oral Presentation)

FY 2011 Publications/Presentations

1. Blanchard, J. "A Roadmap for Tier 1 Telecom Carrier Fuel Cell Installation", OSP Expo, San Antonio, Texas, October 13, 2010. (Oral Presentation)