PEM fuel cell technology: A reliable, cost effective option for critical telecom DC backup power applications requiring prolonged runtimes

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Background

Although the national utility grid is considered reliable across the country, localized conditions and equipment failures or natural events cause unanticipated outages ranging from minutes to several days. Just in the last ten years there have been two major unanticipated grid failures that lasted several days in some areas, affecting millions of people and business operations. Table I below summarizes the causes of large blackouts affecting major population centers. Equipment failure is the leading cause, followed by Wind/Rain natural weather events.

For the telecommunications, Cable TV (CATV), and Traffic Signal backup power systems, VRLA batteries have been used cost effectively and reliably to provide uninterruptible back-up power to these critical networks for hours of runtime during an outage, nominally eight hours or less.

The diesel engine (compression ignition) is the most commonly used prime mover in stationary standby power generators for telecommunications (wireless and wire line) and CATV back-up power applications for grid outages lasting more than eight hours to several days. For critical communications and traffic signal sites without a stationary diesel generator installed, mobile diesel, and spark-ignited gasoline or propane fueled generators ("generator on wheels") are utilized to provide prolonged runtimes, as required. Most VRLA batteries are inadequate for the runtime required to meet these extended outages. Because of the size and weight limitations of batteries, industry professionals have looked to stationary diesel generators, with large sub-base fuel storage tanks, as the solution for prolonged runtime applications. While this technology has been proven commercially and done the job reasonably well over the past several decades, end-users are seeking an alternative technology that can reliably and cost effectively address the many known negative characteristics and tough Environmental Protection Agency (EPA) regulations placed on generator technology.

Table 1. Large Blackouts in the United States

Statistics for Outage Cause Categories

	% of events	Mean size in MW	Mean size in customers
Earthquake	0.8	1,408	375,900
Tornado	2.8	367	115,439
Hurricane/Tropical Storm	4.2	1,309	782,695
Ice Storm	5	1,152	343,448
Lightning	11.3	270	70,944
Wind/Rain	14.8	793	185,199
Other cold weather	5.5	542	150,255
Fire	5.2	431	111,244
Intentional attack	1.6	340	24,572
Supply shortage	5.3	341	138,957
Other external cause	4.8	710	246,071
Equipment Failure	29.7	379	57,140
Operator Error	10.1	489	105,322
Voltage reduction	7.7	153	212,900
Volunteer reduction	5.9	190	134,543

Source: *Trends in the History of Large Blackouts in the United States*, http://www.uvm.edu/~phines/publications/2008/Hines_2008_blackouts.pdf.

Notes: Totals are greater than 100% because some events fall into multiple initiating-event categories.

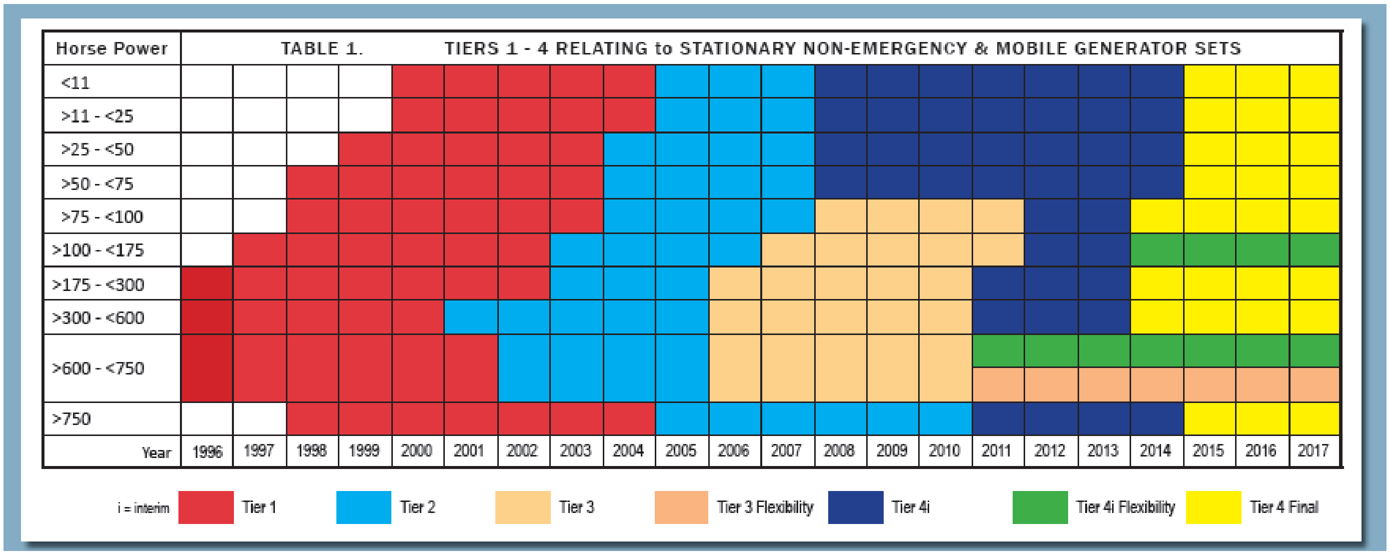
Negative Characteristics of Diesel Generators

EPA Emissions Regulations (www.epa.gov)

The US Environmental Protection Agency (EPA) began to enforce limitations on exhaust emissions for off-highway compression ignition diesel engines in 1996, and later in 2006, for stationary diesel generator sets. These regulations were introduced in steps (known as Tier levels) and became more stringent over the subsequent years and have had a major effect in substantially lowering the levels of nitrogen oxide (NOx), carbon monoxide (CO), particulate matter (PM) and non-methane hydrocarbons (NMHC). With the implementation of the latest “Tier 4 Final” emissions regulations in 2014-2015, NOx emissions from diesel generators will be reduced by 99% from their pre-1996 levels. The EPA emissions regulations will vary by the engine horsepower rating and not the kW nameplate rating of the generator. To meet these stringent emissions standards, diesel engine manufacturers have employed exhaust after treatment systems, like selective catalytic reduction (SCR), diesel particulate filters (DPF), exhaust gas recirculation (EGR) systems, and other engine design changes which have significantly increased the up-front capital costs of the generator, in some cases doubling the up-front capital costs of the generator.

Throughout most of the country, stationary diesel-engine and gas-engine generator sets used strictly for emergency standby power (ESP) are exempt from EPA Tier 4 Interim (2008) and Tier 4 Final (2014-2015) regulations. Also, because ESP units typically run less than 200 hours per year, their emissions have been judged to have an insignificant impact on local air quality. In fact, there are no time limits on running ESP generators in true emergency situations due to utility outages or equipment malfunctions. However, mobile diesel and spark-ignited generators use for temporary backup power (generator on wheels) are subject to the stringent Tier 4 emissions regulations (See Table 1 below).

It is very important to note that state and local municipalities may dictate even stricter emissions limits over and above the EPA levels. These would apply to stationary diesel and spark-ignited ESP generators that were exempted from EPA Tier 4 mentioned above. These locations across the country, known as non-attainment areas, include dense or large population centers where very high local emissions exceed the EPA air quality recommendations. Examples of non-attainment areas include the State of California, many New England states, cites of Atlanta Georgia, and Houston Texas. These are just some of the examples of non-attainment areas across the United States that will have strict emissions regulations even over and above the EPA Tier levels, driving up the capital costs of both stationary and mobile diesel generators used in telecom and CATV networks.



Certain states and municipalities also have strict noise ordinances which may require enhanced sound attenuated enclosures for the generators, which will also contribute to the higher up-front capital costs.

High 10 Year Total Cost of Ownership

In addition to the higher up-front capital costs noted above, the frequency and costs of on-going preventative maintenance (PM) required for diesel generators, depending on the size, can range from $1,000 to $2,500/year, further driving up the Total Cost of Ownership (TCO) over a ten year operating period. One example of a PM schedule for a diesel generator is shown below:

Maintenance items	Service time				
	Daily	Weekly	Monthly	6 months	Yearly
Inspection	X				
Check coolant heater	X				
Check coolant level	X				
Check oil level	X				
Check fuel level	X				
Check charge-air piping	X				
Check/clean air cleaner		X			
Check battery charger		X			
Drain fuel filter		X			
Drain water from fuel tank		X			
Check coolant concentration			X		
Check drive belt tension			X		
Drain exhaust condensate			X		
Check starting batteries			X		
Change oil and filter				X	
Change coolant filter				X	
Clean crankcase breather				X	
Change air cleaner element				X	
Check radiator hoses				X	
Change fuel filters				X	
Clean cooling systems					X

Figure 1. Example Diesel Generator PM Schedule

There are also operating and environmental conditions that may require more frequent and additional PM, further escalating the TCO of a diesel generator. These include:

- Operating the diesel generator for 24 continuous hours or more per utility outage
- Exposure to extreme temperatures
- Exposure to weather and salt water.

Rooftop Deployments – A "No-Go" for Diesel Generators

Diesel generators, in addition to propane or gasoline fueled generators typically cannot receive a permit to operate on a building rooftop. There is a risk of secondary fire if there is a fuel leak that pools below the generator and onto the roof surface. Most major metropolitan cities like New York, Chicago, San Francisco, and Los Angeles have little available real estate ground level to install a generator for new, existing cell site or small cell deployments, making rooftop locations desirable. While batteries can be placed on rooftops, because of weight and space limitations, batteries are typically limited to eight hours of runtime or less. Thus the obvious need for an alternative technology that can easily obtain a permit for prolonged runtime rooftop applications.

Wet Stacking

Wet stacking is a term that originally described a diesel engine dripping a thick, black, and gooey substance from its exhaust piping or as they are sometimes known by the name, "stacks." This serious condition is caused by operating the diesel engine at light load for extended periods, sending unburned fuel and soot into the exhaust system. Over a long period of time operating in this manner, this wet stacking condition can seriously degrade engine performance and useful life.

As mentioned earlier, most standby generators for telecom and CATV facilities have a diesel engine as the prime mover. Many of these generators are routinely tested at no load or at light loads, instead of at or near full load. Also, in telecom applications, generators are typically oversized when initially specified to anticipate future load growth which most of the time never happens. In general, diesel generators that are not regularly exercised or operated at 33% to 50% of the nameplate rating are at risk for wet stacking over the long term.

Mechanical Equipment Failure

As mentioned earlier, unanticipated grid outages lasting several days can result in mechanical equipment failure due to the many moving parts of a generator system. During the 2003 grid outage, which affected millions of customers and many telecom sites in the northeast corridor, there were numerous reports of diesel generator failures that were running continuously for more than 24 hours per day. These failures were not due to running out of fuel, they were due to mechanical component failures, as these generators are not designed for continuous runtime duty.

Other Negative Characteristics of Diesel Generators

Some other issues with diesel generators that have caused industry professionals to seek an alternative solution include:

- Failure to start when called upon, possibly due to inadequate PM.
- Starting battery theft, which in some cases cannot be avoided.
- Diesel fuel treatment additives required for diesel fuel sitting unused for prolonged period of time, resulting in even higher operating costs. Standby power generation is considered severe duty for fuel since it is can be stored for a year or more in sub-base fuel tanks and is rarely turned over through use or circulation, even during periods of regular exercising. Water created by condensation and microbial contamination can consume a fuel system in a matter of just a few days, clogging fuel filters and corroding every part of the fuel system.
- Diesel fuel theft, due to the high cost of this fuel.

Is there an alternative backup power technology that addresses all these issues noted that can totally replace the diesel generator function for telecom and CATV applications sized for 100kW and below? The answer is a resounding yes, and it is the PEM fuel cell solution.

A Brief History of Fuel Cells

The origin of fuel cells can be traced as far back as 1776, when the 13 American Colonies declared their independence from Mother England! A renowned scientist at that time, Henry Cavendish, discovered that water is not an element, but rather a compound formed when hydrogen reacts with oxygen.

Decades later in 1839, Dr. Christian F. Schönbein hypothesized that this reaction also generated an electrical current--a hypothesis that Sir William Robert Grove confirmed in 1839 when he experimented and assembled what he described as a “gas voltaic battery” – what is now known as the first “fuel cell.” Because of his work in advancing the hypothesis, Sir William Robert Grove, a Welsh lawyer turned scientist was given the esteemed title: “The Father of Fuel Cells.” The production of an electric current is by means of an electro-chemical reaction between hydrogen and oxygen, not the combustion of fossil fuels.

What is today known as a “fuel cell” (a term first coined nearly thirty years after Sir William Grove’s experiment, by Charles Langer and Ludwig Mond in 1889, to describe their efforts using coal gas) has now been under development for nearly two centuries.

However, fuel cell technology did not find its first practical uses until the mid to late 1950s, when it began to be employed for mobile applications that would eventually range from space missions to public transportation. Every Apollo and Space Shuttle mission by NASA, from the early 1960's through today, had fuel cells aboard supplying power and drinking water to the astronauts. As you will see on page 6, water is a byproduct of the electro-chemical reaction of a fuel cell.

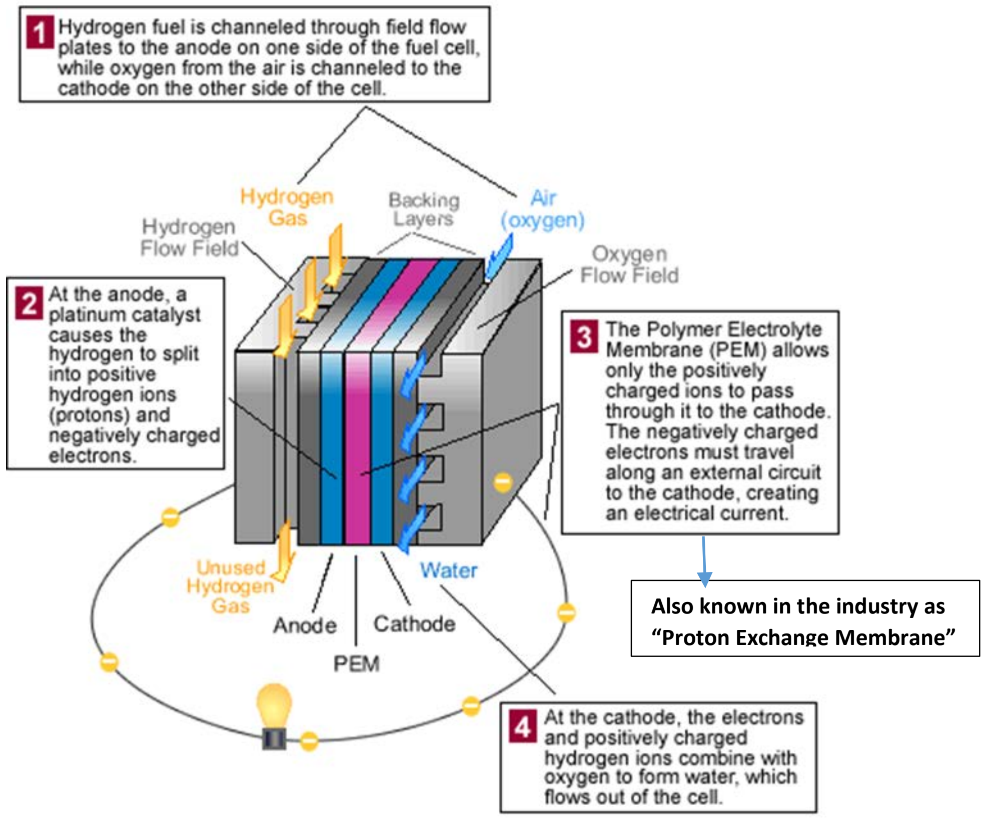
In the past fifteen years, fuel cells have seen widespread implementation in the USA & and around the world, in stationary prime power electric only, and combined heat and power (CHP) applications. PEM fuel cell technology is commercially proven with thousands of deployments, millions of reliable operational hours, while subjected to wide temperature swings in telecommunications back-up power applications. It will be shown that PEM fuel cell technology can supplement battery backup and totally replace the diesel generator function for existing or new critical communication network sites.

PEM Fuel Cells: A Viable Alternative to Diesel Generators

Proton Exchange Membrane (PEM) fuel cells, like batteries, provide DC electricity without combustion through an electro-chemical reaction. However, this is where the similarities end. Unlike a battery, the fuel cell does not need constant recharging to maintain its output voltage. As long as there is a supply of hydrogen fuel, the fuel cell will produce DC power with unlimited runtime and zero emissions at the point of use, which eliminates any EPA or non-attainment area emissions regulations, allowing for simple air permitting, thus making this an excellent alternative to diesel generators for prolonged utility outages (i.e. greater than eight hours).

What is a PEM Fuel Cell and How Does it Work?

A PEM fuel cell produces DC power as a result of a chemical reaction between hydrogen gas and oxygen from the air, in the presence of a catalyst – without any combustion, at very low noise levels. See drawing below which describes each step of the process.

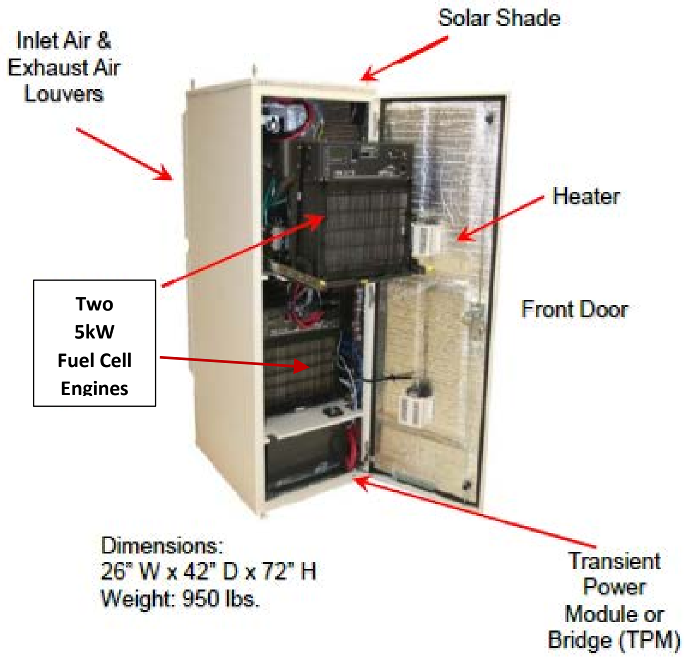


Note:

- Hydrogen is mixed (not burned) with air. This combination, in the presence of a catalyst converts the hydrogen and oxygen (from the ambient air) to DC electricity and water – with zero emissions at the point of use, which can directly support customer sustainability objectives.
- Low temperatures, fast start times (less than 30 seconds for the Altergy Systems design), making the PEM fuel cell ideal for critical CATV back-up power applications: distributed/centralized power nodes, wireless telecom, wire line Remote Terminals (RT) / Central Offices (CO), and traffic signal Outside Plant (OSP) applications.
- No moving parts in cell stack, making for simple and low cost annual preventative maintenance.

PEM fuel cells are modular and scalable from 100W to 100kW to meet the exacting requirements of back-up power applications in the wireless, wire line, CATV, and traffic signal market segments mentioned above. These compact, solid state designs address all the issues associated with diesel generators.

To illustrate the compact footprint of PEM fuel cell technology, see the pictures below for a 10kW telecom application, with 8 hours of fuel storage on-site. These cabinets can be installed adjacent to each other, inches apart, minimizing footprint required (see page 8 for actual PEM fuel cell installations):



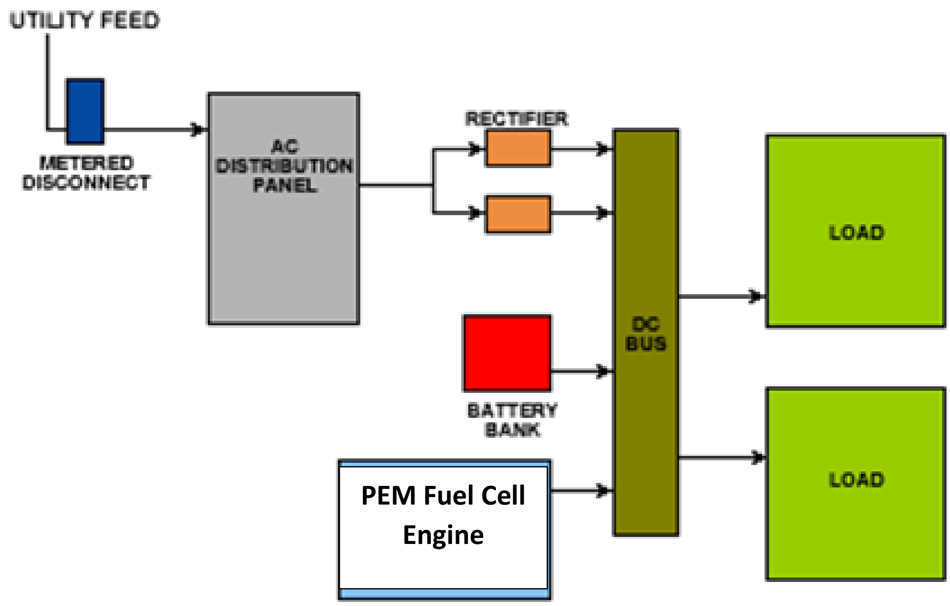
8-Steel Bottle Fuel Storage Cabinet
Provides 80kWh Runtime

The Transient Power Module (TPM) or bridge battery is required to provide the 30 seconds of uninterruptible power to the critical DC telecom radio loads while the fuel cell starts. Note that some PEM fuel cell designs could take 30 minutes or longer to start, which requires a larger bridge battery system, making them less desirable. If there are existing system batteries at a particular telecom installation site (typically 2 to 8 hours of battery backup are specified) they can be used for the bridge power and short duration outages (seconds to a few hours). In this case, the TPM is not required. The fuel cell can provide for runtimes exceeding 8 hours with more on-site H2 storage than shown above, to supplement the system batteries, instead of deploying a diesel generator.

Compressed hydrogen gas (H2) is stored in steel cylinders, and mounted in a weather enclosure, as shown above. Unlike diesel fuel, which requires additives when unused for prolonged periods of time, hydrogen gas requires no such additives, and is ready to consume when needed one day or several years after initial deployment.

With no moving parts in the cell stack, PEM fuel cell PM is simply cleaning or replacing air filters once per year or every 1000 hours of operation, whichever comes first (~ $100/year). The only other ongoing operating cost is the cost of H2 fuel and delivery. Diesel generators on the other hand, as shown earlier, can result in PM costs 10 times as much or more than the PEM fuel cell on an annual basis. This does not include the cost of diesel fuel, which in today’s market is quite high per gallon compared to H2 gas cost per kilogram, and diesel fuel delivery.

For a typical telecom or CATV OSP application, the PEM fuel cells DC output connects directly to the system DC bus, just like the VRLA battery bank, as illustrated below:



Referring to the above illustration, the PEM fuel cell will continuously monitor the DC bus. In a typical wireless telecom 48VDC application, upon a utility or rectifier failure, the batteries would provide the initial uninterruptible power to the critical telecom loads. As the battery power is used, the DC bus voltage will start dropping from say -54VDC to -52VDC, with thresholds selectable in 0.1VDC increments. At the customer selected threshold DC voltage level, the fuel cell would move from the monitoring state (standby) to the start state and power the load for the duration of the outage. When the utility power returns, the fuel cell monitors and senses the return of the utility, waits until stable (wait time is customer selectable), then returns to a standby mode, waiting for the next outage. The fuel cell would supplement the batteries and totally replace the diesel generator function in this typical example.

PEM Fuel Cell Installations

PEM fuel cells have been installed in thousands of locations nationally & globally since the early 2000 timeframe, experiencing wide temperature swings in summer & winter, overcoming the operating temperature extreme issues of diesel generators. With these thousands of installations, and on-going additional deployments, PEM fuel cells are a proven, rugged and reliable back up power solution for your critical OSP applications. Fuel cells are no longer a science experiment or a technology just for niche applications. Some examples of PEM fuel cell installations at wireless tower/cell sites are shown below:

Ground level application, L to R, BTS radio cabinet, PEM fuel cell cabinet, H2 fuel cabinet.

Rooftop application, L to R, BTS radio cabinet, PEM fuel cell cabinet, H2 fuel cabinet.

Regarding rooftop deployments, as mentioned earlier, it is difficult to nearly impossible to obtain a permit to operate a diesel or propane generator on the roof due to potential fuel leaks pooling on roof surfaces and increasing the chances of a secondary fire. If H2 gas leaks, rather than pool – it is lighter than liquid fossil fuels and the air, it quickly rises at 70 feet/minute up and away from equipment and roof, minimizing the chance of fire at the building structure.

With continued improvements in the supply chain, coupled with significant advances in fuel cell stack manufacturing, the upfront capital costs of fuel cells, which have been the major issue in the past, have significantly decreased in the past decade. Rebates & incentives that encourage the use of green and sustainable technology may be available at the State level and an Investment Tax Credit (ITC) is available from the federal level providing $3000/kW or 30% of the total project costs, whichever is less. This is a dollar for dollar reduction in the federal income tax liability for the system owner. No such incentive is available for diesel generator systems. This ITC incentive helps narrow the gap significantly in up-front capital costs between fuel cells and legacy backup power technologies, like batteries and generators.

PEM fuel cells, depending on the design, cell stack components used, balance of plant (BOP) material used, and manufacturing techniques employed, have a design life of greater than 15 years, making them a rugged, reliable alternative to diesel generators.

For prolonged runtime requirements, a typical OSP site (wireless, wire line, CATV, and traffic signal) will deploy 2 to 8 hours of battery backup in addition to an on-site portable engine receptacle where a mobile/portable diesel generator can plug into. Some OSP sites have a permanently installed stationary diesel or propane generator with an Automatic Transfer Switch (ATS) for prolonged runtime needs. Due to the high annual operating costs of PM for the diesel generator solution, in addition to the other negative characteristics noted earlier, PEM fuel cells will provide the lowest 10 year TCO.

Flexible Fueling Options for Deployed PEM Fuel Cell Sites Nationally

Hydrogen gas (H2), the most abundantly used industrial gas nationally, is readily available in most major cities and localities in the USA. For typical OSP applications, the H2 is stored in steel tanks or cylinders, and enclosed in a telecom grade OSP cabinet, as shown in the picture above on page 7. Hydrogen has an excellent safety record for more than 50 years! While hydrogen is a combustible gas, it is been shown to be safer than traditional fossil fuels like diesel, gasoline, propane, and natural gas.

Re-fueling H2 “Fill” trucks use “Fill-In-Place” technology (FIP) today as a means of re-fueling PEM fuel cell sites. See pictures below, as an example of FIP technology. The traditional or old method of “bottle swapping”; having to have access inside the fuel cabinet, disconnecting empty cylinders from the fuel manifold and connecting full cylinders to the manifold, is no longer necessary. With FIP, where available nationally, a fill truck fitted with a Department of Transportation (DOT) certified hose (see below) connected to H2 large storage cylinders on the truck, connects to a fill port located on the fuel cabinet front door. The hose is simply connected to the fill port nozzle, and in just minutes, all the cylinders are re-filled in place, with no handling of the cylinders or access inside the cabinet required. This is a proven, simple, safe, efficient and cost effective method of providing hydrogen refueling to installed PEM fuel cell system sites, providing “unlimited runtime” for the end user.

FIP Port with Nozzle & Pressure Gauge

Fill Hose from Fill Truck

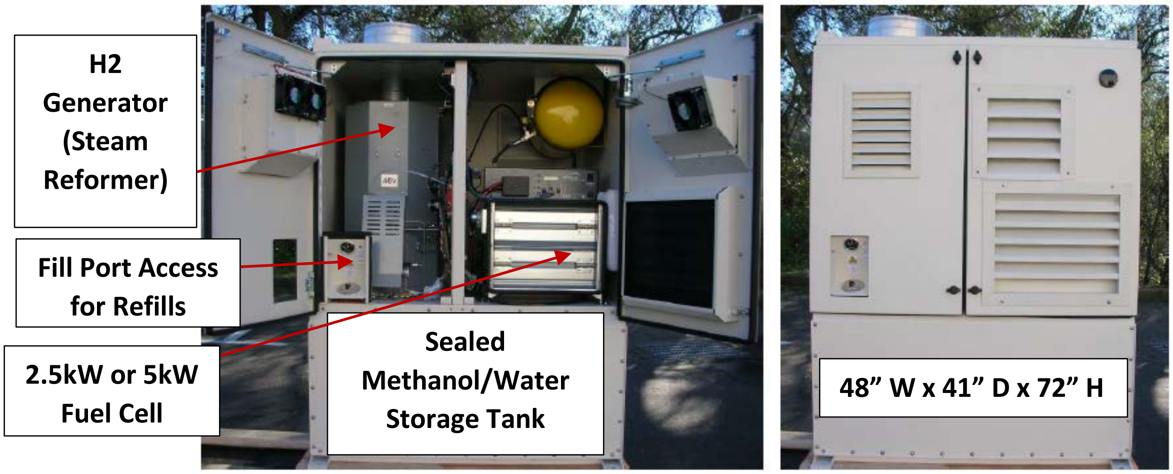
Fuel Cabinet FIP Port, with Small Access Door

Typical FIP Capable H2 Fill Truck

Note: Higher storage pressure, composite cylinders shown above; Aluminum tank, with a carbon-fiber wrap, they store 2X the amount of H2 gas than the standard steel cylinders, for longer runtime needs.

Remember, as long as there is a source of H2 fuel, the PEM fuel cell will continuously and reliably generate the DC output power required for OSP applications, with none of the negative characteristics or limitations of diesel generators.

For remote locations, with no easy access to H2 gas, propane, or diesel fuel, a prolonged runtime solution is still viable with PEM fuel cells using a pre-mixed methanol/water solution and an integrated steam reformer to generate H2 gas on-site. Several sizes of sealed storage tanks are available and provide runtimes in days versus hours, and is ideal for difficult to reach tower/cell sites, or RT sites, etc. Methanol/Water reformer systems, like gaseous H2 fueled PEM fuel cell systems, are commercially proven with hundreds of applications both nationally and globally. The picture below shows an example of an integrated fuel cell power and H2 generator cabinet.



Integrated Fuel Cell and H2 Generator

Summary

As this paper illustrated, with unanticipated utility grid failures nationally, diesel generator extended runtime performance can be unpredictable and affected by a wide variety of factors that have been well known for many years, due to the design and operational characteristics of these systems.

PEM fuel cells, on the other hand, have been shown to be a more cost effective, scalable, reliable, prolonged runtime solution without any of the limitations, high maintenance costs, and environmental issues associated with diesel generators. In thousands of successful installations across the vertical markets discussed in this paper, PEM fuel cells have met or exceeded requirements and are a commercially proven technology that should be considered by end-users as a viable, cost effective alternative to totally replace the diesel generator function.

If you are tired of the issues associated with legacy backup power technologies, and have not looked at PEM fuel cells recently or at all, I hope this paper has shed new light on this clean, reliable, cost effective alternative back up power technology, for serious consideration at existing sites where there will be planned generator replacements or for new OSP sites being considered now and in the future.