Powering Change with Fuel Cells in the Telecommunication Industry

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Hydrogen Fuel Cells provide a promising new method of power generation and energy storage for both mobility and stationary power applications. Hydrogenics Corporation is currently engaged in the design, development, and demonstration of Proton Exchange Membrane (PEM) fuel cells for a wide range of applications, including backup power for telecommunication infrastructure, data centers and other mission critical applications. Extended run backup power has been recognized as one of the early emerging PEM markets. The characteristics of PEM fuel cells offer an economical and efficient alternative to diesel generators and batteries, providing increased reliability and extend run capabilities.

PEM fuel cells convert chemical energy from hydrogen and oxygen into electrical energy. As the hydrogen moves through a catalyst, called a cell, the protons and electrons are split and the electrons travel through a conductor. When the electrons return from the circuit and reconnect with the protons, they mix with oxygen, making the only by product of the electricity generating process, water and heat. Fuel cell systems include not only the fuel cell stack (where the above mentioned electrochemical conversion takes place), but also all of the balance of plant components required to optimize conditions for the reaction within the stack. These components; provide, condition, and control, both hydrogen and air flow to the stack. All of the data provided in this paper, and any references made to fuel cell systems and technology, refer to complete fuel cell power modules (stack and balance of plant components).

The following paper presents the design philosophy, functionality, and technical configuration of PEM fuel cell systems for backup power extended run applications.

1 Design Philosophy and Functionality of Fuel Cell Systems for Back-up Power

The value proposition for fuel cells in many applications is based on two of the primary characteristics of the technology - fuel cells do not generate any harmful emissions, and hydrogen can be domestically produced without the use of fossil fuels. However, the philosophy behind using PEM fuel cells for backup power systems extends well beyond their clean and emission free attributes. Fuel cells also meet the need for increased flexibility and reliability, for a low cost extended run solution. The following provides a summary of the key characteristics of PEM fuel cells which are of interest to the backup power market.

1.1 Proton Exchange Membrane fuel cells for quick start-up.

While some types of fuel cells take a long time to begin producing electricity, PEM fuel cells produce an electric current almost instantaneously, making them the ideal type of fuel cell for backup power applications. Only a very small amount of bridge power is required for the initial seconds of system start-up (section 2.1 presents hybrid architecture solutions which utilize ultra-capacitors or batteries for the initial seconds of bridge power). Once in operation, PEM fuel cells are able to respond instantaneously to load changes. It is also a result of the quick start-up time (and low operating temperature) that PEM fuel cells have long been regarded as the fuel cell of choice for the replacement of the internal combustion engine in the automotive industry.

1.2 Fuel cells and hydrogen storage enable the disassociation of power and energy.

In many ways fuel cells combine the beneficial attributes of both diesel engines and batteries, without the associated compromises. Although fuel cells are similar to batteries as far as converting chemical energy directly to electrical energy, with no mechanical energy transition, fuel cells have the added benefit of utilizing a fuel source, rather than having to recharge to a finite amount of available run time. A fuel cell will run up to its maximum kW power capacity as long as hydrogen is available. If the extended run requirements increase, additional hydrogen storage can be supplied to operate the fuel cell for a longer time period.

Similar to the ability to incrementally supply energy in the form of fuel storage, the modular design of fuel cells, enables systems to be easily configured for additional power from the same fuel supply. Therefore, as the load at a site grows another extra fuel cell can be added in parallel. The modular fuel cell configurations not only allow sites to grow as their power demand grows, but also enables the building of N+1 redundancy into a system configuration. As a result of modularity and scalability on both the energy and power sides of the equation, fuel cells provide unprecedented flexibility to meet any backup power design requirements.

1.3 Systems can be installed indoor, close to the load, or placed in an outdoor cabinet.

Hydrogen is generally placed outdoors, similar to any other fuel. However, since fuel cells do not generate any harmful emissions, they can be placed in indoor environments at the electrical load just as batteries are most often placed today.
There are several additional attributes that make fuel cells ideal for indoor installation for backup power, including their ability to isolate heat rejection in liquid cooled fuel cell systems. In instances where systems are liquid cooled as opposed to air cooled, it is possible to eject the heat generated during operation outside of the equipment room. Thermal management challenges are increasingly becoming more common as power densities also dramatically rise for both telecommunication providers and within data centers. The heat generated from backup power equipment that is air cooled, further compounds these thermal management challenges.

Network operators are also often anxious to place backup power system outside in order to leave more space for revenue generating equipment within the data or telecommunications centre. Unfortunately, for battery based systems this is a high risk proposition due to the dramatic effects that the operating environment's temperature has on the service life of the batteries. Fortunately, fuel cells are not faced with the same challenges and can be placed in outdoor cabinets whose temperature control is relatively moderate (example: between a range of 5 degrees Celsius and 50 degrees Celsius).

An additional characteristic of fuel cells is that they have a limited number of moving parts. This feature creates numerous advantages, one of which is a very low noise level which allows the systems to operate inside a building or in close proximity to neighboring facilities outside. This eases the additional challenge typically associated with placement of mechanical equipment.

1.4 Total cost of ownership for modular fuel cell solutions is less than other extended run options.

The total cost of ownership of a backup power generation system consists of the following elements:

- Engineering costs
- Capital cost
- Installation/start-up costs
- Maintenance costs
- Fuel costs
- Replacement and disposal costs

The design of modular and scalable systems assists in alleviating high upfront engineering design and capital costs. Network operators are able to easily plan for growth and meet a wide variety of multiple facility needs with the same components. Typically, ridged configuration solutions are oversized when initially installed with supply and demand not equated. The rationale driving initial over sizing of units is to accommodate future growth or is as a result of available system components simply exceeding actual requirements.

For infrastructure that demand extended run, conventional technologies for meeting this need typically respond by utilizing a high percentage of the available physical space to install equipment.
It is estimated that the cost of lost space taken up by backup power equipment, vis-à-vis revenue generating equipment, can easily equate to 150% of the capital cost of the backup power equipment. The compact footprint of fuel cell solutions enables more room for revenue generating equipment.

Figure 1 below compares the volumetric energy density in kilowatt-hours per cubic meter of a fuel cell and hydrogen solution versus a battery system for eight hours of run time based on Hydrogenics' HyPM® XR 10 fuel cell technology.

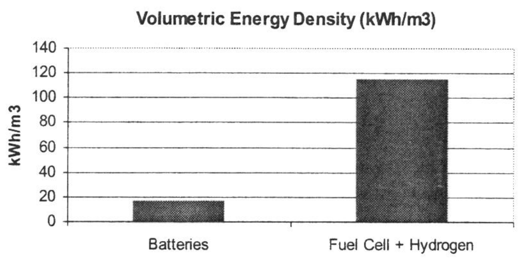

Fig. 1 Volumetric Energy Density Comparison – Based on Hydrogenics Corporation's HyPM® XR 10 fuel cell technology

Volumetric energy density comparisons show that the fuel cell option requires only 4% of the indoor rack space compared to the equivalent battery option, when hydrogen is stored outside. Even when you take into account the outdoor space required for 8 hours of hydrogen storage, the volumetric power density of the complete fuel cell system is six times better, or a 16% improvement over batteries. When the extended run requirement exceeds eight hours, the figures presented improve even further, since only more hydrogen is being added for the same fuel cell.

Since the service life of a fuel cell system is dramatically better than that of batteries, not only are capital costs saved in the initial purchase, but users are also not faced with the high cost of battery replacement and disposal. Estimates indicate that battery replacement (generally done on a 5 year or less interval) can reach 150% of the initial capital expenditure due to the high disposal costs.

2 Technical Configuration

Back-up power systems based on fuel cells can be configured to meet a wide range of electrical requirements – DC power solutions for telecommunications and AC solutions for data centre applications. PEM fuel cell backup systems are generally configured using the utility grid as the primary source of power, so that the fuel cell is used only as a means of backup during a scheduled shutdown or failure of the utility grid. In the case of AC systems, an uninterruptible power supply (UPS) is used to bridge the few seconds required for the fuel cell to come to full load. The UPS system also contains the inverter required to produce the AC output for the load, since fuel cells generate DC power. In the case of a DC power load, fuel cells can be used in combination with ultra-capacitors or batteries.

2.1 Fuel cell solutions designed for instantaneous response in DC power applications utilize hybrid architecture in combination with ultra-capacitors and batteries.

In a hybrid configuration, the ultra-capacitors, or batteries can "float" on the DC bus and provide continuity to the supply of DC power when the utility fails and before the fuel cell system comes to full power (for a few seconds). Figure 2 shows the response of a fuel cell power module in combination with ultra-capacitors to meet the uninterruptible DC requirements often found in the telecommunications industry.

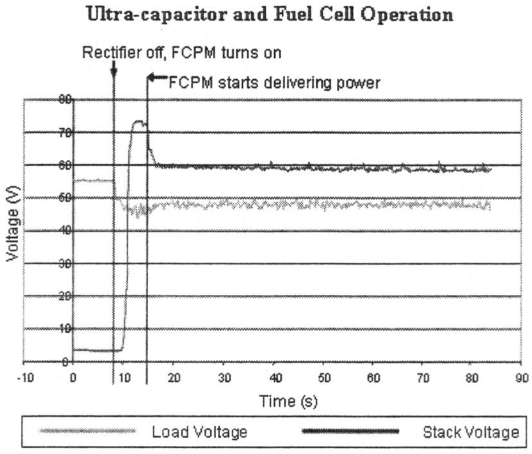

Fig. 2 Hybrid System Operation during Startup – Data from Hydrogenics Corporation

The voltage on the DC bus in Figure 2 is at 56 volts. When grid power is lost (at the 9 second mark on Figure 2), the voltage requirements are met by the ultra-capacitors until the fuel cell stack voltage climbs to meet the voltage requirement (in this case 48 volts DC).

2.2 Fuel cell configurations for AC backup power utilize an uninterruptible power supply as an interface to the load.

For AC power systems, such as those seen in the data centre market, a fuel cell is utilized in combination with a UPS. The role of the UPS is to sustain the initial load until the fuel cell is generating power, and for the necessary power electronics to produce AC power load requirements Hydrogenics Corporation has partnered with American Power Conversion (APC) to offer complete extended run AC power solutions. Hydrogenics is providing the fuel cell systems, while APC is providing power electronics to match the fuel cell voltage output to the input requirements of their UPS system. The two companies are working together to accelerate the commercialization of an economical and efficient product that will provide increased availability and back-up power runtime to address the changing needs of the data centre market.

3 Durability and Reliability

The PEM fuel cell industry has been investing in significant testing and has been able to dramatically improve system reliability and durability. A large amount of this testing has been driven by the leading automotive companies, whose investment

in PEM system development is in the range of hundreds of millions of dollars This has created a strong supply chain for component parts and assisted in lower material costs. The industry is now moving into the field trial and demonstration phase in the backup power market.
The following provides durability and reliability data based on Hydrogenics' PEM fuel cell testing.

3.1 Durability

There are a few fundamental characteristics of fuel cell systems that create an inherently high level of durability.

- Fuel cells only degrade while they are producing power in operation, they do not degrade while in off or stand-by modes.
- Unlike batteries, fuel cells are not adversely affected by cycling profiles, moderate fluctuations in the operating environment temperature or the rate, frequency and depth of discharge.

The durability of PEM systems has dramatically increased over the past few years. Leading PEM developers are now able to show thousands of hours of durability.
Figure 3 below shows the durability of a Hydrogenics' HyPM® 10 fuel cell system during a typical mobility testing cycle.

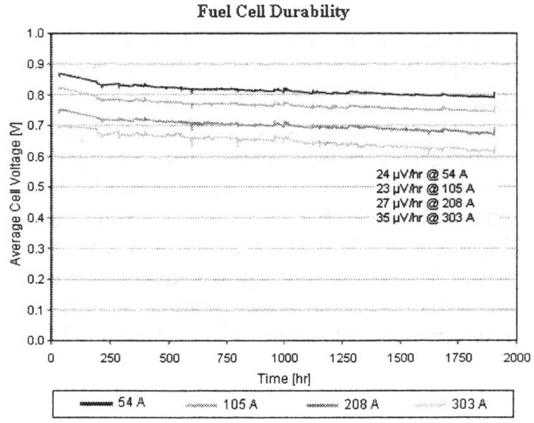

Fig. 3 Fuel Cell System Durability – Data is from a Hydrogenics Corporation's mobility application testing program using a HyPM® 10 fuel cell

3.2 Reliability

Since fuel cells utilize a chemical rather than mechanical means of producing electricity, and have a limited number of moving parts, the systems are inherently more reliable than their combustion engine competitors. Much the same way that durability has increased, Hydrogenics along with leading automotive companies has also proven the reliability of PEM fuel cells to undergo thousands of start and stop cycles. Figure 4 shows that fuel cell voltage degradation is unaffected by start stop cycles. The 5,626 start and stop cycles presented in Figure 4 were completed on a Hydrogenics' HyPM® 10 using three different cycle profiles. The cycles all involved 5 minutes of run time, however the off times varied between 5 minutes, 4 hours, and 10 hours.

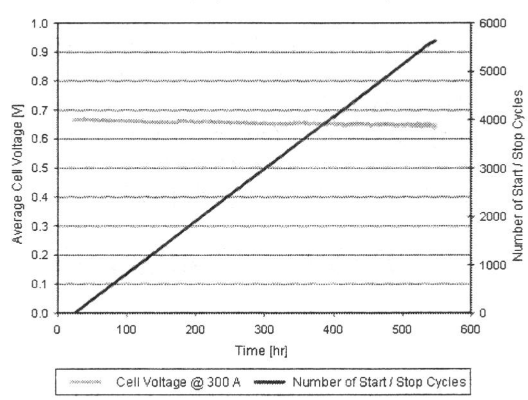

Fig. 4 Fuel Cell Startup Reliability Testing – Data is from Hydrogenics Corporation's testing of HyPM® 10 fuel cell technology

4 Conclusions

Fuel cells are now at the stage of development where they are able to provide a strong value proposition to mission critical backup power applications requiring extended run time. In summary, the value proposition is based on the following two primary factors.

- A lower total cost of ownership.
  - Cost of ownership is impacted most by the lower capital costs, reduced maintenance requirements, and an improved service life of fuel cell systems.
- Improved reliability.
  - The technology characteristics resulting in improved reliability include the reduction in moving parts (also reducing maintenance) and the fact that degradation does not occur when the fuel cell system is not in operation.

The fuel cell industry has also been able to gain valuable insight into the design of backup power solutions through the successes and challenges faced by other technologies in the market. This is evidenced by the need for modularity and scalable features in systems, which customers have sought, and which fuel cells have been able to respond to.

As more systems are deployed for backup power applications and the technology is adopted in this early market, cost will begin to decrease with higher volume manufacturing and fuel cells will be able to start emerging in other applications, further driving improvements to the existing value proposition for extended run backup power.