Installation of Proton Exchange Membrane Fuel Cells at Residences for Combined Heat and Power

Darrell D. Massie, Ph.D., P.E.
Associate Professor
Dept Civil and Mechanical Engineering
US Military Academy, West Point, NY, USA

Daisie D. Boettner, Ph.D.
Associate Professor
Dept Civil and Mechanical Engineering
US Military Academy, West Point, NY, USA

Cheryl A. Massie, LC
President
Massie+Massie Consulting Engineers
West Point, NY, USA

John H. Kang
Dept Civil and Mechanical Engineering
US Military Academy, West Point, NY, USA

Summary

Three proton exchange membrane fuel cell systems have been installed to provide electrical power and waste heat for three separate residences. The 5 kW fuel cell systems continually operate in a standby power configuration with waste heat used for domestic hot water and space heating. The fuel cell systems operate at steady state providing a preset level of power which is fed into the residence and the utility grid. During periods of utility power outage an automatic transfer switch disconnects the residential power source from the grid, providing power from the fuel cell system with battery. Residential loads are prioritized during this time to accommodate the preset level of power available from the fuel cell system. When grid power is reestablished, the transfer switch automatically synchronizes the fuel cell system with the grid and then reconnects the two. This paper describes issues relating to installation of the fuel cell systems.

1. Introduction

The US Department of Defense (DoD) spends over $1 billion a year to provide heat and power to their buildings. Additionally, they require innovative power solutions for mobile applications such as base camps, mobile equipment, and ground and aerial vehicles. Given this, the DoD is interested in the development of alternate power sources, and supports research and testing to pioneer technologies associated with micro power plants. The DoD currently supports research in proton exchange member (PEM) fuel cells due to their high efficiency, flexibility in size, low operating temperature, and low emissions.

In addition to broader funding for fuel cell demonstrations at military facilities, recent funding has targeted PEM fuel cells for residential applications. The goals for this program are to assess fuel cells for providing power in support of sustainable design and to study their viability as an alternative power source to the DoD; to study the effect fuel cells have on the DoD's ability to construct, operate and maintain facilities; to assess installation and operation issues associated with the use of PEM fuel cells; and to stimulate growth in the fuel cell industry, Holcomb (2004).

This paper focuses on the issues associated with the installation of three residential PEM fuel cell systems located at a military base in New York. The fuel cells have been configured to recover waste heat for domestic hot water and space heating. The manufacturer is responsible for fuel cell system installation, all system operation and maintenance, and site restoration.

2. Fuel Cell Configuration

The fuel cell systems use natural gas as the fuel source. Autothermal reforming of the natural gas provides hydrogen reformate for the fuel cell reactions. The fuel cell systems are rated at 5 kW power output with three user selected settings of 2.5, 4 and 5 kW. A battery, contained within the fuel cell unit, provides transient load following capability. An inverter converts the DC supplied electricity to usable AC electricity for the residence. Since the military installation is centrally billed and the electrical demand is always much greater than fuel cell provided power, there is no need to operate using a load-following scheme. The fuel cells are configured to continually operate as standby power. With this configuration, power is continually supplied in parallel with grid-produced electricity. Any fuel cell system generated power that is in excess to residence demand is fed back into the grid. During periods of grid outage, an automatic transfer switch disconnects the fuel cell system from the grid and the fuel cell system provides a preset level of power to the residence. When grid power is reestablished, the transfer switch automatically synchronizes with the grid and then reconnects the fuel cell system.

The fuel cell system waste heat recovery provides for domestic hot water and limited space heating. Since the fuel cell systems are installed as a retrofit, piping and installation costs for total space heating would be prohibitive. Fuel cell specifications are provided in Table 1.

Table 1 Fuel cell specifications.

Unit size	Base Unit with integral skid: 84"L x 32"W x 68 1/4"H (excludes 22" exhaust stack)
Installation location	Outdoor
Electrical configuration	Grid standby
Power output/setpoints	2.5, 4 and 5 kW
Data collection and monitoring	Remote via phone line
Output voltage	120 VAC @ 60Hz
Certification	Integrated System CSA International Certified; Inverter UL Listed
Power quality	IEEE 519
Emissions (steady-state)	NOx < 1PPM SOx < 1PPM
Standard operating conditions	Temperature: 0-104^{o}F Elevation: 0-750 Feet Noise< 65 dBa @ 1 meter
Waste heat utilization	System efficiency dependent on external cogeneration loop temperature and flow rate.
Electric only efficiency	26% @ 2.5kW 25% @ 4.0kW 23.5% @ 5kW
Projected overall efficiency	50% @ 2.5kW 55% @ 4.0kW 50% @ 5kW

The system installed includes a wall-mounted, customer interface panel that allows emergency shut-off of the fuel cell system. The fuel cell manufacturer provided instructions for emergency shut-off procedures. The customer interface panel also shows the operating status of the fuel cell system, comparing the current power setting to the actual power produced. An alarm notifies the occupants when the battery drops below a set threshold, when a power outage occurs, and when the residential power demand exceeds the capability of the fuel cell system.

3. Installation Issues

This section provides resident observations as the fuel cells were installed. Since the residents are engineers, their interest and knowledge of the technology are most likely beyond that of a typical resident.

3.1 Siting

Several factors affected the ultimate location of each fuel cell system in relationship to the exterior of the residence. The reformer stack protruding from the top of the system must be at least ten feet from the closest window by governmental regulation. The manufacturer placed the systems on temporary gravel foundations at all locations.

The manufacturer desired to limit the exterior piping distances between the fuel cell system and the residence. The piping requirements include the fuel cell cooling water loop, the deionized water loop, electrical, control and natural gas connections. Piping entry to all three residences was made through a basement window, where the installer removed one pane from the window and replaced it with a plywood board. All of the pipes were located above ground and were routed through holes drilled into the plywood. The installer insulated the exterior cooling water loop pipes and deionized water pipes with foam pipe sleeves and installed a plywood cover to shield the pipes from open view.

Since these fuel cell systems are scheduled to be removed after only one year, temporary measures were used. For a permanent installation, a concrete pad in lieu of a gravel foundation is recommended. Additionally, burying the pipes rather than above ground piping is recommended.

3.2 Water Supply Temperature

The ideal setpoint temperature for domestic hot water is not entirely clear. The user-selected setpoint is typically a balance between safety and water usage. ASHRAE (1999) recommends water storage temperatures in the 60°C (140°F) range so as to limit the potential for Legionelia pneumophila growth. Since Legionelia pneumophila bacteria requires moisture for survival, water temperatures between 27-49°C (80-120°F) promotes its growth, ASHRAE (1999). Ciesieiki et al. (1984) determined that Legionelia pneumophila can colonize in hot water systems maintained at 49°C (115°F) or lower.

Excessively hot tap water supply is extremely dangerous and at temperatures above 46.1-49°C (115-120°F) can in a short period of time result in serious or fatal scald burn injuries. The degree of injury is dependent upon skin sensitivity to heat and exposure time; children and older adults being at highest risk of scald injury. Although water heater manufacturers often recommend that installers set thermostats at 49°C (120°F), the plumbing engineering community continues to recommend hot water systems be designed with higher temperatures to reduce the threat of Legionelia pneumophila growth.

One method to help mitigate the balance between bacterial growth and risk of scald injury is to maintain the domestic hot water at or above 60°C (140°F) and then blend it with cold water such that tap water temperatures do not scald occupants. However, thermostatic mixing valves complying with ASSE 1017 are designed to control temperature from ±3.8°C (±7°F), depending on the size when flowing at the required flow rate. It should also be noted that ASSE 1017 has no test for compensation during pressure fluctuation. As such, the mixing valve needs to be located at the hot water source to minimize pressure fluctuations between the hot and cold water lines. To prevent bacteria growth downstream of the blending valve, supervised periodic flushing of fixture heads with 77°C (170°F) water is also recommended in hospitals and health care facilities.

In one of the residences, the pre-installed tap water temperature was measured at 52°C (125°F). The adult residents manually controlled the tap temperature to avoid scald. The water temperature was maintained at this temperature to accommodate dish washing and laundry, well short of the ASHRAE 1999 representative value of 60°C (140°F) for this purpose.

After installation of valves and pipes, the installed anti-scald valve had a design range to allow water temperatures of 27-49°C (80-120°F), lower than the pre-installation recorded temperature. The actual maximum temperature was measured at 47°C (116°F), slightly short of the advertised range, but within manufacture's tolerance. However, the temperature was well short of pre-installation recorded temperature desired by the occupant. Assuming that water heater temperature could be maintained to 60°C by the fuel cell system and given that ASSE 1017 recommends a high temperature source (8°C above maximum mixing temperature), we recommend that any anti-scald valve have a design range of 27-55°C (80-130°F) so that a full range of household tasks may be performed. If a future fuel cell system has an even higher water supply temperature, we recommend that the upper range of an anti-scald valve be even higher.

3.3 Design of Heat Recovery

There are several methods for configuring fuel cell waste heat to recover domestic hot water and space heating. One consideration in the design is the requirement that domestic hot water often requires a hotter temperature than space heating. This is because the water tank (sink) is at a higher temperature, typically 60°C (140°F) than required for a room, typically 21°C (70°F). Given that a PEM fuel cell rejects heat at 60°C, the logical design is that heat recovery for hot water should be placed upstream of space heating. Space heat located upstream of hot water heating would result in an inability to maintain 60°C in a water tank. This implies that during periods when fuel cell heat is used for domestic hot water recovery, temperatures may drop (de-rating heat registers) below that required for meaningful heat recovery.

A parallel configuration might be considered, but this would add piping complexity and it could be difficult to balance flow in pipe runs of different lengths. At all three sites, domestic hot water heat recovery hardware was located upstream of space heat.

3.4 Retrofit Complexity

The significant amount of piping (natural gas, water, deionized water) as well as the routing of electrical wiring, makes retrofit a challenge. The basements in these residences are all unfinished and thus exposed piping and conduit is acceptable. Installation to ensure that piping is not exposed in finished rooms poses a greater challenge. Figures 1, 2, and 3 illustrate the extent of piping and the large number of required connections. Since this is a retrofit project,

Figure 1. Complex piping required near domestic hot water tank in residence 1.

Figure 2. Complex piping required near domestic hot water tank in residence 2.

Figure 3. Complex piping required near domestic hot water tank in residence 3.

the actual piping configuration in each residence is different. Although the plumbing contractor's work appeared professional by every standard, the amount of piping required in a limited amount of space, made the installation difficult.

This demonstration was the manufacturer's first experience with combined heating and power (CHP). Miscommunication about piping for space heat resulted in a redesign of the piping flow pattern supporting the heat exchangers. This coupled with the very harsh winter of 2002-2003 posed installation challenges. Large snowfalls inhibited travel by installation crews and limited access to the fuel cell units that were located outdoors. The fuel cells have been heavily instrumented, however, delays in installing the fuel cells have delayed operation and data collection in time for this paper.

3.5 <u>Fire and Safety Issues</u>

Although fuel cell details are often found in the literature, few people understand the details of how they operate or even what components comprise a fuel cell system. Firefighters often are among those who have not been introduced to fuel cell technology and lack an understanding of equipment and chemicals that might be located within a fuel cell unit.

For one installation, tapping into the gas line to feed the fuel cell caused a gas leak that was not noticed until construction workers departed. When the occupant returned home for the evening, she noticed the leak. The local fire department was notified and asked to assist. Firemen, being cautious, were trying to be prepared for any possible hazard. As the occupant oriented the fire department on the problem, the firemen revealed that they did not know how a fuel cell worked and consequently did not know how to effectively fight a fire had one been present.

As new technologies are developed and integrated into residential use, consumers as well as public safety officials need to understand the underlying operating principles. Until such time as fuel cell systems are in wide residential use, appropriate measures should be incorporated into the fuel cell installation. One suggestion is labeling all piping with the content and flow direction to assist orientation of the occupants and emergency personnel. Additionally, manufacturer-produced pamphlets that describe the basic operation and schematic of the fuel cell subsystems could help bridge the knowledge gap.

3.6 Reliability Issues

The fuel cell systems were placed on the ground in late December 2002. Installation of the piping and system connection spanned a period of four months. Prior to commissioning of the fuel cell systems, the manufacturer chose to replace the fuel cell stacks in all three systems. Although the authors have no experience with fuel cell reliability issues, replacement of the fuel cell stacks suggests concern about performance and/or reliability of PEM fuel cell membranes that have not been in a controlled environment prior to system start-up.

4. Conclusions

Retrofit installations of fuel cell systems pose practical challenges for residents and manufacturers alike. Design choices, operating set points, utilization of low temperature waste heat and safety issues require understanding and careful design. Designs need to be continually refined and fire fighting personnel need educational training for potential hazards.

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