Case Study: Fuel Cell Micro Grid Operation at the 2004 Democratic National Convention

George P. Berntsen, Fuel Cell Energy

ABSTRACT

The 2004 Democratic National Convention (DNC) in downtown Boston presented an energy challenge. The large, attendant media presence required a great deal of additional power for temporary studios, satellite up-links, etc., that could not be supplied by the constrained electric utility infrastructure.

To meet this need, an independent micro grid was constructed consisting of two rail-mounted diesel-generators and a trailer-mounted fuel cell power plant. The fuel cell was a DFC300 produced by FuelCell Energy, Inc. The DFC300 is a 250 kW rated power plant, capable of both grid connected and grid independent operation. The DNC micro grid represented the first application in which the DFC300 operated in parallel with diesel generators independent of the electric utility grid.

In addition to explaining the fuel cell power plant operating modes, this article describes the specific planning, challenges and operating results of the unit in the DNC micro grid. It will also examine the potential benefits of fuel cells in future micro grid applications.

FUEL CELL TECHNICAL OVERVIEW

The fuel cell used in the 2004 DNC micro grid was a 250 kW DFC300 produced by FuelCell Energy, Inc. of Danbury, Connecticut. The fuel supply was pipeline natural gas.

The DFC300 consists of three major sub-systems: the mechanical balance-of-plant (MBOP), the direct fuel cell (DFC) module, and the electrical balance-of-plant (EBOP). Refer to Figure 1 for the following description of the DFC300 fuel cell power plant.

Mechanical Balance-of-Plant

The MBOP contains the piping, valves, heat exchangers and other equipment necessary to prepare the fuel gas (typically natural gas or digester gas) for supply to the fuel cell module. The fuel gas is first treated to remove sulfur. This impurity is either added by gas distributors as an odorant or is present as a constituent of digester gas. The fuel gas is then heated several hundred degrees using exhaust heat from the fuel cell module. As it is heated, the fuel gas is humidified with high purity water. This prevents coking of the hydrocarbon fuel gas and supplies the water needed for the hydrocarbon-to-hydrogen reforming reaction. The heated, humidified fuel gas is then supplied to the fuel cell module.

Direct Fuel Cell (DFC) Module

The DFC is a high temperature (approximately 1200°F), carbonate electrolyte fuel cell. Its patented technology allows hydrocarbon fuel to be directly supplied to the fuel cell, where it is internally reformed to yield the hydrogen needed for the fuel cell electrochemical reaction. This greatly simplifies the fuel preparation process compared to external reforming fuel cell technologies. Fresh air supplies the oxidant for the fuel cell reaction.

The basic fuel cell products are heat, water and DC electricity. The use of a hydrocarbon fuel instead of pure hydrogen results in carbon dioxide as an additional emission.

The high temperature fuel cell module exhaust gas is used in the MBOP to heat the fuel gas as described above. Following this on-board heat recovery, the exhaust gas temperature is high enough (approximately 700°F) to produce high pressure steam for co-generation applications.

The DC electrical power output from the DFC Module is applied to the power conditioning unit portion of the electrical balance-of-plant.

Electrical Balance-of-Plant (EBOP)

The EBOP provides power conversion and distribution functions. The power conditioning unit (PCU) is based on solid state inverter technology, It draws DC current from the DFC module and converts it to synchronized, three-phase, 480V, AC power. A typical grid parallel load configuration is depicted in Figure 2.

During normal, grid-connected, operation, the fuel cell power plant

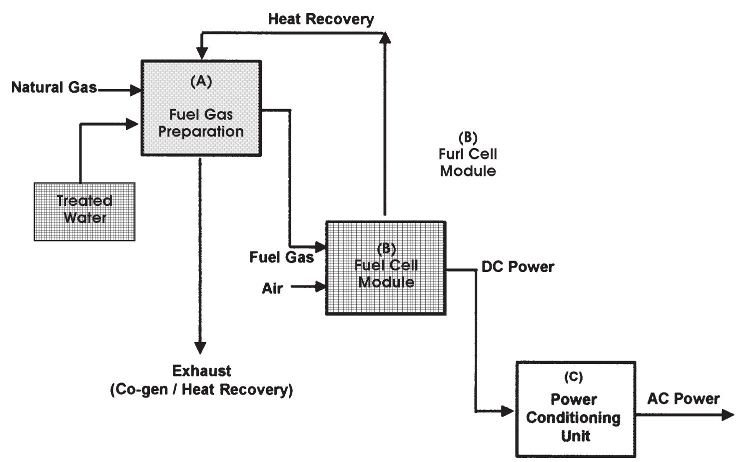

Figure 1. DFC300 block diagram

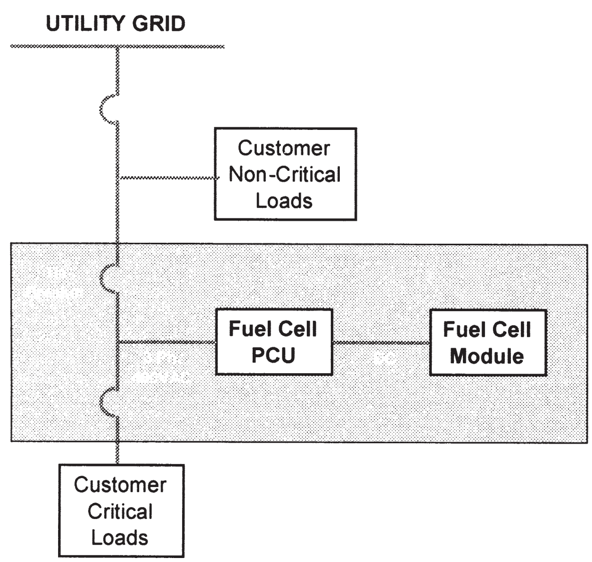

Figure 2. DFC300 typical configuration

is synchronized to the utility grid. Loads are distributed so that the fuel cell power plant carries the customer critical loads and some of the customer's non-critical load. The fuel cell operates at a base load. Load variations are absorbed by the utility grid.

If the power plant detects that the utility grid is degraded or lost, it switches to grid independent mode. It does this by opening its tie breaker to isolate from the utility grid and transferring to a frequency and voltage support mode. In this mode, the PCU output continuously adjusts to match the customer critical load while maintaining rated frequency and voltage.

DNC MEDIA CITY MICRO GRID

The 2004 Democratic National Convention provided a unique opportunity to demonstrate fuel cell power plant operation in a stand alone, micro grid. The substantial media presence directly outside the Boston Fleet Center required a large supply of electrical power to service temporary studios and communications and support equipment. The local utility infrastructure could not supply this additional load so it was decided to configure a temporary micro grid.

Figure 3 shows a simplified one-line diagram of the 2004 DNC micro grid. Power was produced and distributed as 60 Hz, 3-phrase 480V.

Two rail-mounted, 1.5 MW, diesel generators provided the backbone of the micro grid. The fuel cell power plant was connected in parallel with the diesel generators through its tie breaker and operated in the grid connected mode as described earlier. Thus, the fuel cell power plant was synchronized to the frequency and voltage established by the diesel generators and carried a set amount of micro grid load. The diesel generators provided the micro grid load following function.

Micro Grid Capacity & Load Matching

The design basis for sizing the micro grid generators was that the loss of any generator would not result in the loss of the micro grid operating at the maximum expected load.

In actuality, instead of a maximum load of 1.5 MW, the micro grid load never exceeded 650 kW. The excess capacity arose from over estimating of required load by the multiple media entities, conservative rounding errors and available generator sizes. The capacity "over kill" is understandable given the temporary and critical nature of the micro grid; however, it did lead to less than optimal operation. Under-loaded diesel generators have difficulty maintaining proper frequency and voltage and may begin to exhaust uncombusted fuel oil. To ensure both

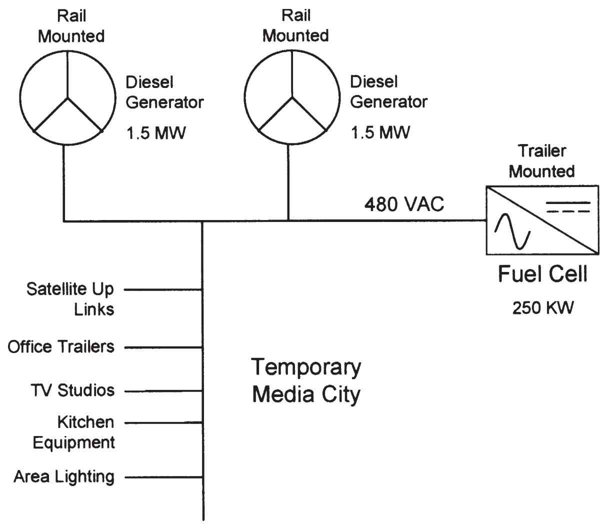

Figure 3. DNC micro grid diagram

diesel generators were carrying sufficient load to prevent these problems, only 50 kW of load could be dispatched to the 250 kW rated fuel cell power plant.

Fortunately, the fuel cell power plant has good turn down characteristics and operated continuously at this low power level without issues.

An optimally matched micro grid would take better advantage of the fuel cell power plant's higher electrical efficiency and ultra low emissions.

Micro Grid Energy Efficiency

Operating the fuel cell power plant at or near rated load would increase energy efficiency by achieving the rated electrical efficiency of 47%. In addition, because of the temporary nature of the 2004 DNC micro grid, no provision was made to utilize the high quality exhaust heat from the fuel cell power plant. In an optimum micro grid, this 700_F effluent would be used for steam production, building heating and/or absorption chilling and could result in overall energy efficiencies of up to 80%.

Protective Relay Settings

The standard DFC300 power plant complies with IEEE-1547, "IEEE

Standard for Interconnecting Distributed Resources with Electric Power Systems." To prevent negatively impacting the utility grid reliability and safety, IEEE-1547 establishes, among other things, protective relay settings. These are intended to ensure a distributed resource (in this case, the fuel cell power plant) quickly isolates itself from the grid in the event of an electrical disturbance.

While planning the DNC micro grid application, concern was raised as to how stable (or "stiff") the micro grid voltage and frequency would be. Consideration was given to widening the protective relay settings to allow the DFC300 to ride through a larger range of voltage and frequency transients. Wider settings, however, could negatively impact the DFC300's ability to successfully transition to grid independent operation. Given project schedule constraints and the need to thoroughly retest the unit with any new settings, it was decided to retain the IEEE-1547 protective relay settings.

On two occasions during operation of the micro grid, the IEEE-1547 protective relay settings were exceeded because of load transients. In both instances, the DFC300 successfully isolated itself from the micro grid by opening its tie breaker. The unit continued generating power in this grid independent mode to carry its own parasitic loads. This precluded time consuming plant shutdowns and restarts. Twenty seconds after the micro grid electrical parameters returned to within the protective relay settings, the DFC300 automatically synchronized to the micro grid, closed its tie breaker and commenced a load ramp back to its kW set point in the grid connected mode.

In an ideal micro grid, less restrictive protective relay settings could be implemented and tested to ensure that the fuel cell power plant only isolated itself from the micro grid under severe load fault conditions while still being able to successfully transition to grid independent operation.

AN IDEAL MICRO GRID APPLICATION

In an ideal micro grid, fuel cells would dominate the generation capacity to maximize energy efficiency and minimize emissions and noise. The micro grid load profile would be thoroughly defined and evaluated so that the generation capacity and load requirements would be optimally matched.

To maximize energy efficiency, the ideal micro grid would utilize carbonate fuel cells such as the DFC300. Carbonate fuel cells have the highest electrical efficiency and the highest quality exhaust heat compared to other commercially available fuel cell and distributed generation technologies (see Figure 4).

The ideal micro grid would service heating, as well as electrical loads. The fuel cell power plant's high temperature, ultra-clean exhaust would provide thermal energy for building heating, process steam, and absorption chilling.

Micro Grid without Utility Grid Connection

A utility grid connection may not be available because of the remoteness of the micro grid's location or if the utility is unable or unwilling to provide standby power and receive exported power. In a completely isolated micro grid, a gas-fired diesel generator could be employed to provide load following and black start capability. It would also be sized to supply replacement capacity during fuel cell power plant maintenance outages. Load management controls would be implemented to ensure the most favorable generation load sharing is automatically achieved. Without a utility grid connection, the generators' protective relay setpoints would not have to comply with IEEE-1547 and could be relaxed to achieve the most advantageous balance between riding through momentary disturbances and isolating from true electrical faults.

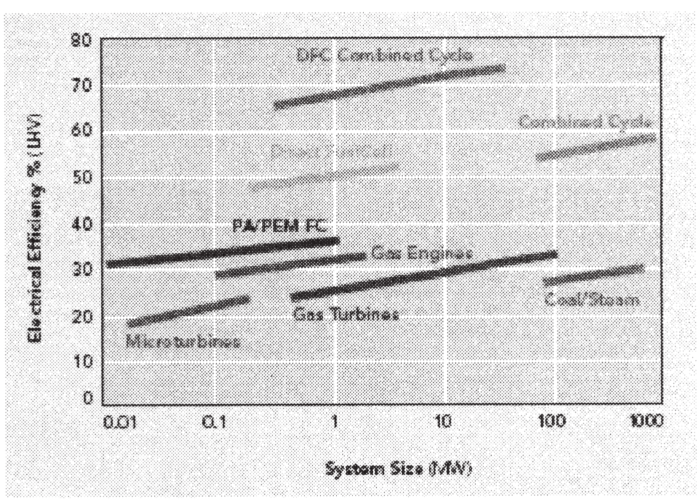

Figure 4. Efficiency comparison

If a utility grid connection is available, the grid could provide the functions of the diesel generator described above.

Micro Grid Fuel Source

In addition to natural gas, fuel cell power plants are successfully operating on locally produced digester gas from sewage treatment plants and breweries. If available, locally produced fuel sources would greatly enhance micro grid operating independence.

SUMMARY

The 2004 Democratic National Convention media city provided an excellent opportunity to deploy a fuel cell power plant in a completely isolated micro grid. Lessons learned from planning and executing this project provides insight into development of future micro grids, which make the most of the following benefits:

- High reliability
- Independence from utility supplied energy
- Ultra-high energy efficiency
- Environmental-friendliness

Resources

"Overview of Direct Carbonate Fuel Cell Technology and Products Development," ASME International First International Fuel Cell Science, Engineering and Technology, Rochester, NY April 21-23, 2003

IEEE-1547-2003, "IEEE Standard for Interconnecting Distributed Resources with Electric Power Systems"

"Fuel Cells – The Clean and Efficient Power Generators" Proceedings of the IEEE, Vol. 89, No. 12, December, 2001

ABOUT THE AUTHOR

George Berntsen is the manager of electrical and controls engineering at FuelCell Energy, Inc in Danbury, CT. He has over 20 years experience in the nuclear and fuel cell power industries including design engineering, operations, maintenance, and training. He has a B.S. in instrumentation and electronics technology from the University of the State of New York and is a graduate of the Navy Nuclear Propulsion Program. Mr. Berntsen may be contacted at *gberntsen@fce.com*.