

# how it works

## Inverter is key to fuel-cell success

By Bill Schweber, Executive Editor

**FUEL CELLS GET THE ATTENTION, BUT THEY ARE USELESS WITHOUT THEIR POWER-CONVERSION SUBSYSTEM.**

**T**HE MEDIA PERIODICALLY GO into a fuel-cell frenzy, rhapsodizing about the possibility of using these cells as a near-perfect source of electrical power. And why shouldn't they? Fuel cells combine air-derived oxygen with hydrogen from hydrocarbons, such as natural gas, and quietly produce electricity, heat, and

water vapor (Figure 1). Fuel cells produce no polluting emissions, such as those you would get from a conventional turbine or internal combustion engine, and virtually no moving parts. It all seems so simple, pure, and natural.

The visions of a fuel cell's potential are diverse. They include fuel cells powering cars, operating as backup or even primary power for your home from a shed-sized fuel-cell system, and providing power for larger commercial buildings and computer installations. Such systems can produce significant power: A pair of fuel cells producing 400 kW powers the LED-based Nasdaq sign in Times Square (Reference 1).

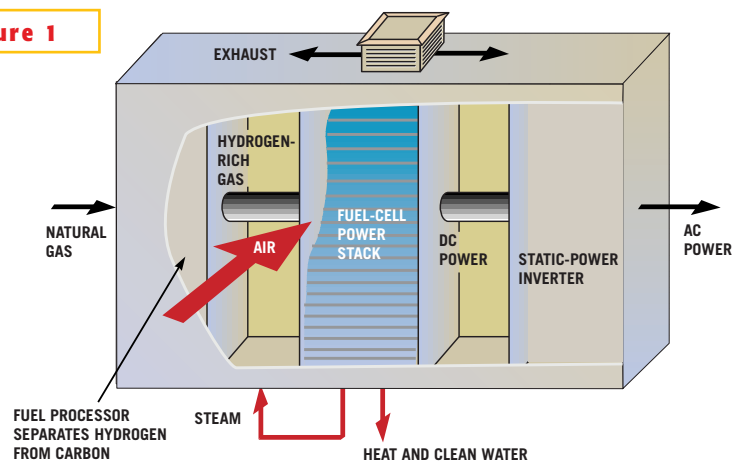
Unfortunately, it's difficult to make fuel cells the best choice in most applications. Although journalists write at length about the fuel cells themselves, and many references to cell technologies exist, most discussions gloss over the fact that you cannot directly use the fuel cell's electrical output (see sidebar "Fuel cells offer history, diversity"). To transform this relatively low-voltage dc output into a reliable and efficient source of power that is comparable in performance and cost with the conventional ac grid, you need a carefully designed electrical subsystem that accounts for the unavoidable

characteristics of a fuel cell. Despite the challenges, many companies now provide complete fuel-cell-based power systems at various power levels for different applications (references 2 to 4).

Like most conventional electrochemical batteries, to which fuel cells are distantly related, each cell has a nominal output voltage of about 1V. Therefore, designers normally stack cells in series to provide higher nominal output voltages, such as 24 or 48V. Still, you are dealing with a relatively low-voltage/high-current dc source, which makes it difficult to achieve electrical-conversion efficiency, especially over a wide load range. The inverter system must convert the fuel cell's output while accommodating inevitable changes in load and the response time of the fuel cells.

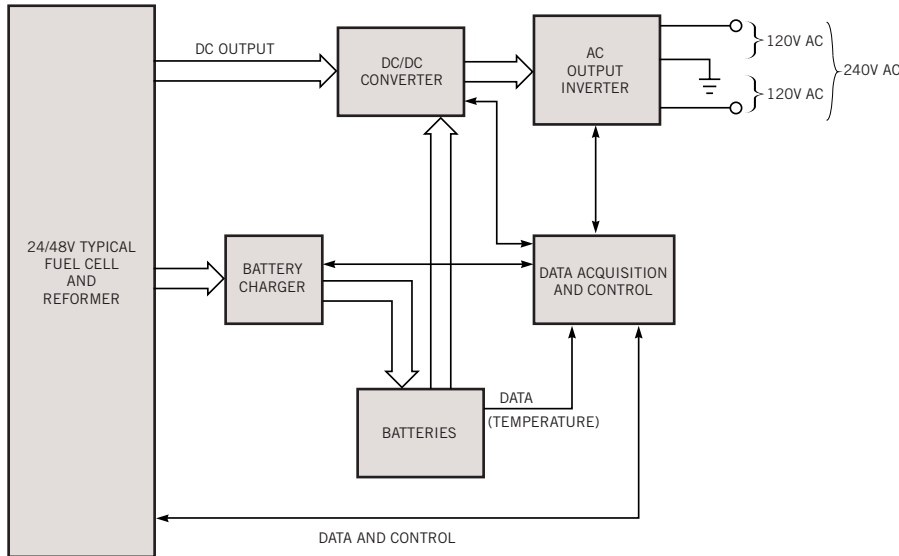
The dc output of the cells varies with their load and age and with a polarization curve that is a function of the electrochemistry. In addition, a fuel cell is relatively slow to respond to load changes, due to

Figure 1



**A complete fuel-cell system converts hydrocarbons and oxygen into dc and then ac power. The waste heat that the cell stack also generates either preheats the reactants or acts as a secondary power generator.**

Figure 2



Converting the dc output of the fuel-cell stack into standard ac power requires several electronic subsystems and supplemental, rechargeable batteries.

the mass of its reactants, thermal lags, and reaction time of its hydrocarbon reformer. They are best suited for relatively steady loads that have no fast load transients (no Pentium-type loads for *these* cells). But with the right design, fuel cells can handle reasonable peak-to-average load ratios of about 2-to-1. A 24V, 3-kW nominal fuel-cell array develops at 20 to 50V, depending on load and other factors, whereas 48V in an 8-kW-unit stack ranges from 45 to 90V.

The challenge for the inverter circuitry is to maximize a fuel cell's overall performance, power output, quality, and efficiency, from the low-voltage, high-current, slow-responding source. Much of today's design activity concentrates on the midrange power levels, roughly comparable with the 3 to 5 kW

that a household needs. This level is where vendors will have the greatest potential demand—if the cost decreases—for supplementing or supplanting conventional power-generation and -transmission facilities. Vendors also have considerable interest in fuel-cell-based systems of approximately 100 kW for small office buildings and computer facilities and for institutions such as hospitals, that need reliable, on-site, primary power sources or grid back-ups. Higher output arrays are practical, as the New York Nasdaq sign tangibly demonstrates, and a 1.9-MW demonstration project also exists in Santa Clara, CA, operating under a Department of Energy contract.

The inverter system consists of several subsystems (Figure 2). The unconditioned dc output of the cell

## FUEL CELLS OFFER HISTORY, DIVERSITY

Fuel cells are sources of electrical power with a long history. Using hydrogen and oxygen to produce electrical current, jurist and amateur physicist William Grove first demonstrated the effect in Britain in 1839. As chemical sources of electrical energy, fuel cells seem like batteries, but they are not batteries in our normal use of the term. They generate power continuously from applied

fuel, rather than by using only a limited supply of stored fuel. Their efficiency is about 40%, which is about 10% higher than conventional grid power plants.

A handful of common fuel-cell types exist, including proton-exchange membrane, phosphoric acid, molten carbonate, and solid oxide (references A and B), each with differing characteristics and attributes.

### REFERENCES

- A. Wolk, Ronald, "Fuel cells for homes and hospitals," *IEEE Spectrum*, May 1999, pg 45.
- B. Thomas, Sharon, and Marcia Zalbowitz, "Fuel cells—green power," Los Alamos National Laboratory, [www.education.lanl.gov/resources/fuelcells](http://www.education.lanl.gov/resources/fuelcells).

array goes to a dc/dc converter, which steps up this voltage to a value that is commensurate with the desired ac output. The higher voltage then goes to an inverter, which develops an ac waveform that you can use. These inverters can be sophisticated, using PWM techniques that a DSP governs to achieve high efficiency while generating sine waves that have THD figures of less than 5%—the standard industry goal—despite different static and dynamic load conditions.

As with the conventional power grid, a single-phase, 240V-ac line provides this output and splits into two 120V-ac outputs at the service panel. This setup feeds most homes and buildings. Homes often also directly use the 240V line for higher current loads, such as air conditioners and electric dryers. The overall efficiency of the dc/dc converter and subsequent inverter is typically 90%; one of the inverter's design challenges is to maintain this level of efficiency at peak loads (high current) as well as average power levels. The fuel-cell power converter from Satcon Technology Corp is about 2 ft long and provides dual outputs of 10 kW each with a cost target of \$250/kw (**Figure 3**).

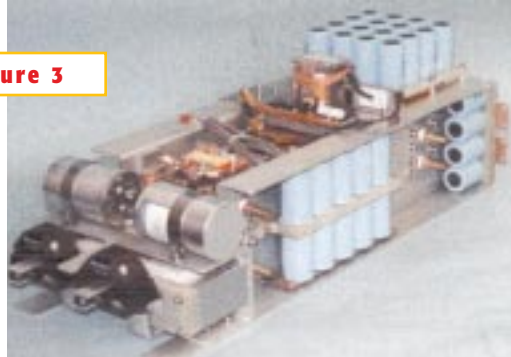
If you think that a fuel cell eliminates the need for batteries, think again. Usually, that's not the case. Rechargeable batteries, often using standard lead-acid technology, are a key part of the fuel-cell electrical system. They serve as an energy buffer, supplementing the fuel-cell output during times of peak load and also providing power during load transients, thus giving the fuel cell time to catch up with load demand. The selection of battery capacity and associated charging/discharging circuitry, therefore, becomes one of the factors that designers must juggle in planning the system. The critical issues involve the amount of the maximum load that the batteries should support versus the fuel-cell capacity, and for how long the batteries should do this.

The electronics must charge the batteries when there is available excess fuel-cell power and provide glitch-free transitions between battery-charging and battery-sourcing mode to the inverter. The data-acquisition and -control module manages charging and discharging; senses current levels, monitors battery and cell temperature, among other factors; and provides some control functions to the fuel cell and its reformer.

Fuel cells are not limited to stationary power applications. In addition to exotic applications, such as providing power for spacecraft and manned space missions, auto companies are working with fuel-cell suppliers to develop electric vehicles that use on-board fuel cells to charge batteries, rather than charging them from an external source. The challenges for this application are far more severe than

for stationary applications, because of size, weight, maintenance, heat, performance, and refueling constraints in vehicles. But fuel-cell systems don't have to be big. There is a demonstration fuel-cell-supply from Motorola Labs (Tempe, AZ) and Los Alamos National Laboratory (Los Alamos, NM), with vol-

**Figure 3**



**This fuel-cell inverter from Satcon provides as much as 10kW on each of two 120V-ac lines, with enough reserve power to trip breakers and start motors. The two ac outputs are on the large connectors on the left.**

ume of less than 1 cubic in. that runs on methanol and powers electronic devices such as cellular phones (**Reference 5**).

The application of fuel-cell-optimized inverters is not limited solely to fuel cells. Other nontraditional sources, such as solar cells, also provide low output voltage along with some of the same challenges as fuel cells and their loads. These applications, though, usually need larger capacity batteries because the basic dc source is not as consistent as fuel cells. □

#### ACKNOWLEDGEMENT

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#### REFERENCES

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