Green Design

Fuel-Cell-Powered Vehicle With Hybrid Power Management

Fuel cells and hydride fuel storage are combined with ultracapacitor energy storage.

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Figure 1 depicts a hybrid electric utility vehicle that is powered by hydrogen-burning proton-exchange-membrane (PEM) fuel cells operating in conjunction with a metal hydride hydrogen-storage unit. Unlike conventional hybrid electric vehicles, this vehicle utilizes ultracapacitors, rather than batteries, for storing electric energy.

This vehicle is a product of continuing efforts to develop the technological discipline known as hybrid power management (HPM), which is oriented toward integration of diverse electric energy-generating, energy-storing, and energy-consuming devices in optimal configurations. Instances of HPM were reported in five prior *NASA Tech Briefs* articles, though not explicitly labeled as HPM in the first three articles: "Ultracapacitors Store Energy in a Hybrid Electric Vehicle" (LEW-16876), Vol. 24, No. 4 (April 2000), page 63; "Photovoltaic Power Station With Ultracapacitors for Storage" (LEW-17177), Vol. 27, No. 8 (August 2003), page 38; "Flasher Powered by Photovoltaic Cells and Ultracapacitors" (LEW-17246), Vol. 27, No. 10 (October 2003), page 37; "Hybrid Power Management" (LEW-17520), Vol. 29, No. 12 (December 2005), page 35; and "Ultracapacitor-Powered Cordless Drill" (LEW-18116-1), Vol. 31, No. 8 (August 2007), page 34.

To recapitulate from the cited prior articles: The use of ultracapacitors as energy-storage devices lies at the heart of HPM. An ultracapacitor is an electrochemical energy-storage device, but unlike in a conventional rechargeable electrochemical cell or battery, chemical reactions do not take place during operation. Instead, energy is stored electrostatically at an electrode/electrolyte interface. The capacitance per unit volume of an ultracapacitor is much greater than that of a conventional capacitor because its electrodes have much greater surface area per unit volume and the separation between the electrodes is much smaller.

In comparison with conventional power management in which batteries are used to store energy, HPM offers many advantages, including the following:

Figure 1. This **Fuel-Cell-Powered Utility Vehicle** has been used to demonstrate the practicability of hybrid power management.

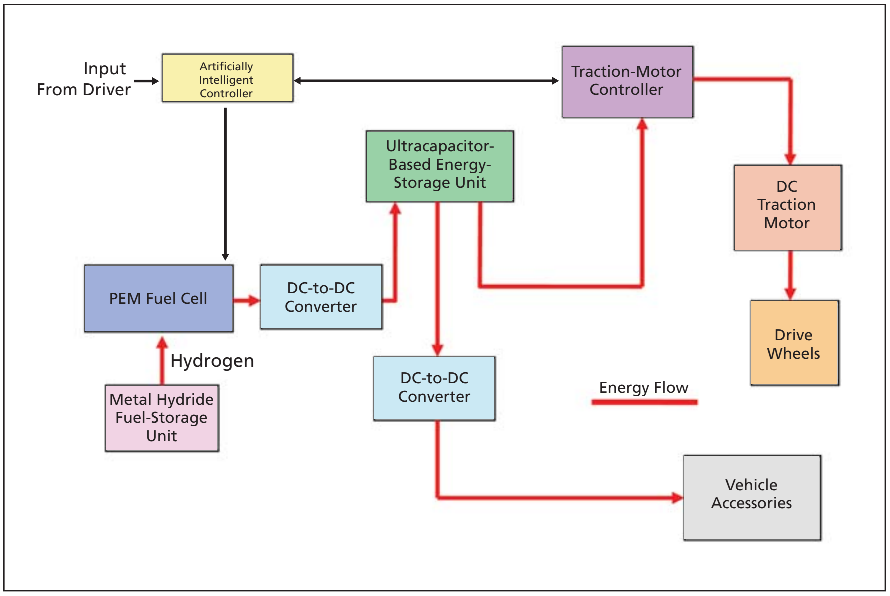

Figure 2. The **HPM System** of the vehicle shown in Figure 1 differs from the power-management systems of conventional hybrid electric vehicles in several major features, including the use of fuel cells (instead of an internal-combustion engine), the use of hydrogen as the fuel, the storage of hydrogen in the form of a metal hydride (instead of a compressed or liquefied gas), and the use of ultracapacitors (instead of batteries) for storing electric energy.

- Power-control circuits for ultracapacitors can be simpler than those for batteries.
- Whereas a typical battery can be charged and discharged about 300 times, an ultracapacitor can be charged and discharged more than a million times.
- The longer lifetimes of ultracapacitors greatly reduce life-of-system costs and reduce adverse environmental effects, inasmuch as it will probably never be necessary to replace and dispose of ultracapacitors in most applications, whereas batteries must be replaced frequently.
- Disposal problems and the associated contributions to life-of-system costs are further reduced because the chemical constituents of ultracapacitors are less toxic and less environmentally harmful than are those of batteries.
- Excellent low-temperature performance makes ultracapacitors suitable for storing energy in applications at temperatures too low for batteries.
- The consistent performance of ultracapacitors over time enables reliable operation not possible with batteries.
- Unlike batteries, ultracapacitors can be safely left completely discharged for indefinitely long times.
- Whereas the charge-discharge efficiency in conventional power management using rechargeable batteries is typically about 50 percent, the charge-discharge efficiency in HPM typically exceeds 90 percent.

Figure 2 depicts the relationships among the various subsystems of the HPM system for the present fuel-cell-powered utility vehicle. At the beginning of operation, the PEM fuel cells are started and used to charge the ultracapacitors. As operation continues, the fuel cells continue to recharge the ultracapacitors while electric energy is drawn from the ultracapacitors (just as energy is drawn from a rechargeable battery in a conventional hybrid vehicle) to drive an electric traction motor that propels the vehicle. In a conceptual alternative version of the vehicle, photovoltaic cells would be used (in addition to or instead of fuel cells) to charge the ultracapacitors. In another conceptual version, some additional recharging would be gained by use of regenerative braking.

Large transient loads are imposed on the traction motor of this or any electric vehicle. Large transient loads shorten the operational lifetimes of PEM fuel cells. By smoothing out the transient loads applied to the PEM fuel cells, the energy-storage devices (in this case, the ultracapacitors) increase the operational lifetimes of the fuel cells and make it possible to utilize fuel cells smaller than would be necessary if the fuel cells alone were required to satisfy the peak power demand. An optimized combination of PEM fuel cells and ultracapacitors makes it possible to obtain high energy and power densities.

The storage of the hydrogen fuel in the form of a metal hydride is a major feature of the design of this system, intended to overcome the disadvantages of the prior approaches to storing hydrogen as a compressed gas at room temperature or as a cryogenic liquid. Storage in a metal hydride can be accomplished more safely and efficiently, at relatively low pressure, without refrigeration.

This work was done by Dennis J. Eichenberg of Glenn Research Center. Further information is contained in a TSP (see page 1).

Inquiries concerning rights for the commercial use of this invention should be addressed to NASA Glenn Research Center, Innovative Partnerships Office, Attn: Steve Fedor, Mail Stop 4–8, 21000 Brookpark Road, Cleveland, Ohio 44135. Refer to LEW-18281-1.

Fine-Water-Mist Multiple-Orientation-Discharge Fire Extinguisher

Rechargeable system discharges 100 percent of its contents regardless of extinguisher orientation.

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A fine-water-mist fire-suppression device has been designed so that it can be discharged uniformly in any orientation via a high-pressure gas propellant. Standard fire extinguishers used while slightly tilted or on their side will not discharge all of their contents. Thanks to the new design, this extinguisher can be used in multiple environments such as aboard low-gravity spacecraft, airplanes, and aboard vehicles that may become overturned prior to or during a fire emergency. Research in recent years has shown that fine water mist can be an effective alternative to Halons now banned from manufacture.

Currently, NASA uses carbon dioxide for fire suppression on the International Space Station (ISS) and Halon chemical extinguishers on the space shuttle. While each of these agents is effective, they have drawbacks. The toxicity of carbon dioxide requires that the crew don breathing apparatus when the extinguishers are deployed on the ISS, and Halon use in future spacecraft has been eliminated because of international protocols on substances that destroy atmospheric ozone. A major advantage to the new system on occupied spacecraft is that the discharged system is locally rechargeable. Since the only fluids used are water and nitrogen, the system can be recharged from stores of both carried aboard the ISS or spacecraft. The only support requirement would be a pump to fill the water and a compressor to pressurize the nitrogen propellant gas. This system uses a gaseous agent to pressurize the storage container as well as to assist in the generation of the fine water mist.

The portable fire extinguisher hardware works like a standard fire extinguisher with a single storage container for the agents (water and nitrogen), a control valve assembly for manual actuation, and a discharge nozzle. The design implemented in the proof-of-concept experiment successfully extinguished both open fires and fires in baffled enclosures.

The proof-of-concept design weighs less than 20 lb (9 kg) and can be easily scaled up or down in size depending on the application. The design is fully self-contained and modular with no complex piping to thread through a crowded habitation module, and mounting is simplified.

The liquid agent is water, or water with additives to enhance the fire suppression capability for specific fire hazards. Compatible gases include nitrogen, argon, or other common nonflammable gases. Each fluid constituent is held in the container by a valve. Design features inside the storage tank make it possible to easily discharge all of the fluid as a uniformly dispersed