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A PHOTOVOLTAIC/FUEL CELL POWER SYSTEM FOR A REMOTE TELECOMMUNICATIONS STATION

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ABSTRACT

The Schatz Energy Research Center (SERC) in cooperation with the Yurok Tribe has designed, built, installed and operated a stand-alone power system integrating photovoltaic and proton-exchange membrane (PEM) fuel cell technologies to operate a remote radio-telephone repeater station. Located within Redwood National Park in northwestern California, the station is the most critical link in the Tribe's telecommunications system.

Primary power for the station is provided by a conventional PV system with battery storage, but the PV system alone cannot carry the load during the winter rainy season. Whenever necessary, the fuel cell system starts automatically and provides clean, reliable, quiet power that is consistent with the National Park Service's (NPS) conservation ethic.

This paper describes the operation of the PV-fuel cell system for the period from November 1999 through June 2000. The fuel cell ran for 3239 hours during this period, providing reliable backup power without interruption.

SETTING AND PROBLEM

The SERC/Yurok power system and the telecommunications repeater it supports are located on top of Schoolhouse Peak (3100 ft, 950m) in Humboldt County, California, in the southeastern corner of Redwood National Park. The site is accessible year-round by dirt road and is situated some sixty road miles (95 km) or thirty air miles (50 km) from Eureka, the county seat and location of the system's intertie to Pacific Bell's regional telephone service. The power system and repeater are housed in an NPS fire lookout tower in direct line of sight to Eureka.

The project originated when the Yurok Tribe set out to provide telephone service to residents of remote portions of the Yurok Reservation. The reservation consists of a two-mile-wide corridor of land straddling the lowermost reach of the Klamath River, below its confluence with the Trinity River. In this deep, forested canyon telephone lines are not available and cellular phone service is out of range. The Tribe's solution was to create a radio-telephone network to provide phone service to the tribal health center and offices, with eventual expansion to provide phone service to two schools and some two hundred residences.

In order to link the reservation to the Pacific Bell network, it was necessary to install three repeater stations. Tribal technicians identified Schoolhouse Peak as the ideal site for the main repeater. However, this site's location inside Redwood National Park meant that the Tribe had to devise a means of powering the repeater compliant with the NPS's ban on installing fossil fuel generators. Photovoltaic power was the obvious solution, given the fire lookout tower's unobstructed solar window. However, the site is prone to long periods of winter rain and overcast skies. A large number of PV modules and batteries would have been required to make a PV-only system work reliably under these conditions.

Upon learning of the Tribe's need, SERC Director Peter Lehman proposed a hydrogen fuel cell as backup to the PV power system. The NPS gave its permission to install a fuel cell as a clean backup energy alternative, and the Tribe and SERC negotiated a cost-sharing agreement.

SYSTEM DESCRIPTION

PV System

The 24-volt PV system consists of twelve 65-watt Siemens SP65 12-volt modules (arrayed as six series pairs wired in parallel), ten Solar Electric Specialties 12SC225 12-volt, 225 amp-hour deep cycle batteries (arrayed as five series pairs wired in parallel) and a Solar Electric Specialties PV Series charge controller/monitor.

NPS design guidelines permitted only direct mounting of the panels on the existing fire lookout tower. Thus, the PV modules are flat-mounted on the tower's south-facing wall, which tilts about 7° from vertical. This steep mounting angle permits high energy collection on clear winter days but results in relatively poor solar energy capture during the summer.

Fuel Cell

The fuel cell is a 32-cell PEM stack with a 140 cm^2 membrane cross-section. The membranes are Gore PRIMEA 5510s. SERC engineers designed and fabricated the stack in-house. It operates on hydrogen delivered at approximately 3 psig (120 kPa). A solid-state, voltage controlled switch turns the stack on when battery voltage falls below 25.2V and switches it off when voltage rises above 25.8V. Air is provided to the fuel cell by a small centrifugal blower. Cooling is achieved using ambient air blown onto the stack surface from beneath by a pair of muffin fans. These fans were determined to be superfluous during the winter season and were temporarily disconnected, leaving natural convection as the sole cooling mechanism.

Hydrogen

The hydrogen supply for the system consists of twelve #44 industrial gas cylinders manifolded together. Cylinder pressure is initially 2000 psig, resulting in 60,000 standard liters total storage. Two pressure regulators reduce the line pressure to about 100 psig, then to about 3 psig for delivery to the fuel cell. Replacement cylinders are delivered to the site as needed by a local industrial gas supplier. During the winter rainy season, a delivery is required approximately every two months. In the summer, despite its nearly vertical orientation, the PV array carries the great majority of the load, thus making hydrogen deliveries unnecessary.

Load

The load is a telecommunications repeater transceiver. Continuous power demand is approximately 100 watts DC. Parasitic loads for the fuel cell system include the air blower, the cooling fans (when needed), supply solenoids, voltage controlled switches, and the hydrogen purge, totaling approximately 24 watts. As data acquisition is not integral to system operation, it is not considered a parasitic load in calculating system efficiency.

Safety

In order to ensure safe unattended operation of the PV/fuel cell system, multiple safety features have been incorporated. When one of several sensors are tripped, the system will shut down automatically and a normally-closed hydrogen delivery solenoid valve will close. Sensors include: 1) a hydrogen gas detector at the fuel cell stack which trips at 25% of the lower explosive limit, 2) an ambient flame/high-temperature sensor within the fuel cell enclosure, and 3) a high temperature sensor within the stack.

In addition, the stack is contained in a non-combustible enclosure within the fire tower and the enclosure is ventilated directly to outdoors. The interior of the fire tower meets the National Fire Protection Association's (NFPA) definition of a non-hazardous location. The compressed hydrogen is stored in a separate steel shed adjacent to the fire tower. The shed is considered an NFPA Class 1, Division 2 hazardous location. All components in the shed are compliant with this classification.

Monitoring

SERC provided the fuel cell system with a remote data acquisition and transmission subsystem. Parameters monitored include: fuel cell voltage and current, ambient and stack temperatures, hydrogen storage pressure, and voltage of the data acquisition subsystem. Battery state-of-charge (SOC) is inferred from battery voltage. Since charge and discharge currents are small, this method is reasonably accurate.

Data are downloaded to the SERC laboratory via cell phone each day. The same system can be used to initiate a safety shutdown from the lab.

OPERATING CONDITIONS

The Schoolhouse Peak telecommunications station is one of three remote serial stations passing signals between the Yurok Reservation and the Pacific Bell facility in Eureka. The other two stations, at Wiregrass and Miners Creek, are also PV-powered. These stations are located outside the national park and are thus able to use ordinary generators as power back-up. Early in the installation phase of the telecommunications network, all the PV modules were stolen from the Miners Creek site. In order to continue the project on existing funding while the Tribe awaited settlement of an insurance claim on the stolen equipment, four of the sixteen panels designated for the Schoolhouse Peak site were diverted to Miners Creek. Due to this unplanned change, the PV array at Schoolhouse Peak produces 25% less energy than it was designed to. This has resulted in the fuel cell running significantly more hours than was anticipated in the system design in order to make up the energy deficit. The fuel cell has thus been pressed into unexpectedly rigorous field service during its first eight months in use. The fuel cell performed extremely well throughout the cloudy winter season, when solar availability was at an annual minimum.

The Tribe has recently been paid its insurance claim on the stolen PV equipment. In the coming months, the Tribe plans to restore to the SHP site the four modules that were temporarily installed at Miners Creek. In addition, the Tribe is purchasing four 100-watt Siemens SR-100 modules for installation on the lookout tower guardrail. These modules will be tilted at 20° below horizontal for optimal summer solar gain, thus complementing the near-vertical mounting of the existing modules, more favorable for winter solar gain. The addition of these new modules should decrease fuel cell operating time significantly.

SYSTEM PERFORMANCE

During seven months in operation without a single unplanned shutdown, the system proved its reliability through an entire winter, when demand on the fuel cell backup is greatest. By June, 23, 2000, the system amassed 3239 hours of operation over 229 days in service (thus running 59% of the time), completed 177 start-stop cycles, and kept the batteries at an average 76% SOC, as shown in Figure 1. Overall gross stack efficiency for this period was 64% (lower heating value) and net system efficiency was 48% (LHV).

Figure 2 shows fuel cell current and voltage values over a typical winter operating period. Note that the fuel cell ran during most of this period due to inclement weather, which prevented the PV array from keeping the batteries charged.

On June 24, 2000 the fuel cell overheated and was taken out of service for repair. The failure occurred when ambient temperatures at the site increased sharply. A stack cooling fan had been disconnected during the winter season in order to reduce the parasitic load and improve system efficiency. During a warm weekend, stack temperature increased, apparently resulting in outgassing of the resin used to seal the graphite separator plates. Consequently, the plates became porous causing the fuel cell to fail.

The fuel cell has been disassembled and the graphite separator plates are being sealed with a surface treatment process that will be much more tolerant of high temperatures. We plan to reassemble the fuel cell and reinstall it in time for the next winter season.

ROLE OF FUEL CELL IN SYSTEM BATTERY MAINTENANCE

According to a recent study by Sandia National Laboratories (1), the benefits to battery lifespan of maintaining high battery SOC in PV systems may be greater than has commonly been assumed. Sandia reported that lead-acid batteries that were left discharged for longer periods (seven to thirty days) between recharges showed marked deterioration in their recharge capacities over time, while batteries that were recharged quickly after discharge and given a twelve-hour "finish charge" maintained or even increased their capacities with repeated charging. Another Sandia study suggests that many PV-only systems may be unable to deliver steady current for long enough uninterrupted periods to achieve the recommended finish charge (2).

The Schoolhouse Peak fuel cell's ability to carry the load when the PV array is unable to charge the batteries accounts for the battery bank's consistently high SOC. Furthermore, the low-current trickle charge the fuel cell delivers to the batteries (at a charging rate of approximately C/300) results in slow finish charging of the batteries, as compared to the faster bulk charging accomplished by a conventional backup generator. Slower charging rates result in lower cell temperatures in the batteries (3). We hypothesize that these factors play an important role in extending the working life of the system's battery bank.

In a system using lead-acid batteries where deep discharges are common, a high end-of-charge-cycle voltage, typically 2.50 V/cell (30.0 total battery volts in this nominally 24V system) is required to break down lead sulfate layers that form on the battery plates (4). However, by maintaining high SOC, we have been able to charge the batteries to a maximum daily average voltage of only 26.7 V with no long-term charge capacity loss observed to date.

Given the ban on fossil fuel powered generators at the project site, the system design team might have chosen to build a stand-alone PV-only system and specified sufficient modules and batteries to carry the load through the winter season without a fuel cell backup. (In fact, since there was limited area available for the array, this design option was not available in this specific case.) Under that scenario, however, the batteries might have been subjected to longer, deeper discharges and shorter continuous finish-charge cycles, reducing long-term battery bank capacity.

LESSONS LEARNED

SERC's experiences so far with the Schoolhouse Peak system have resulted in a number of lessons learned that may be applied as modifications to this system and design changes in future SERC PV/fuel cell systems.

- SERC engineers plan to install a temperature-activated fan switch in place of seasonal, manual disconnect for the fan. This will avoid future overheat failures.
- The resin impregnated graphite separator plates will be replaced with surface treated graphite that will be much less temperature sensitive.
- At present, battery condition is monitored solely via battery voltage. To better monitor battery condition, periodic on-site maintenance will include hydrometer measurements of battery specific gravity.

CONCLUSIONS

Based on the foregoing, we conclude that:

1) Apart from the recent high-temperature failure of the separator plates, the fuel cell power system performed extremely well in its role as a clean back-up power generator for the PV system.

2) Preliminary data indicate that inclusion of a fuel cell in the system is promoting good battery health and will extend battery life.

3) All participants in the project, the Yurok Tribe, the National Park Service, and SERC are extremely pleased with the results.

REFERENCES

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Figure 1. Storage Battery Operating History

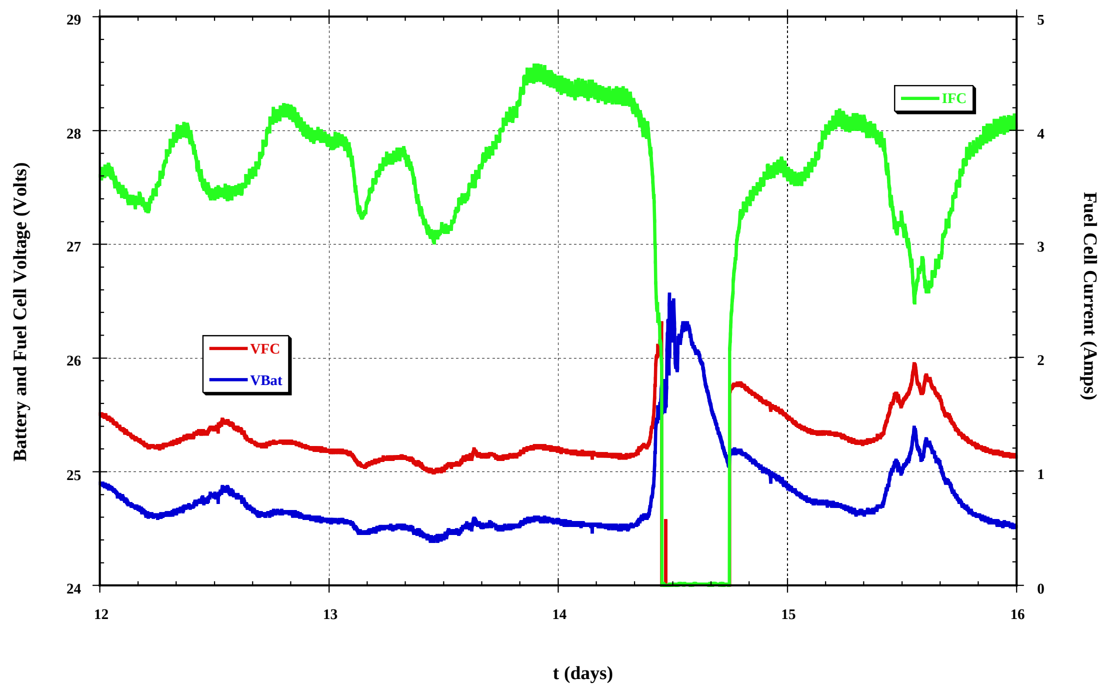
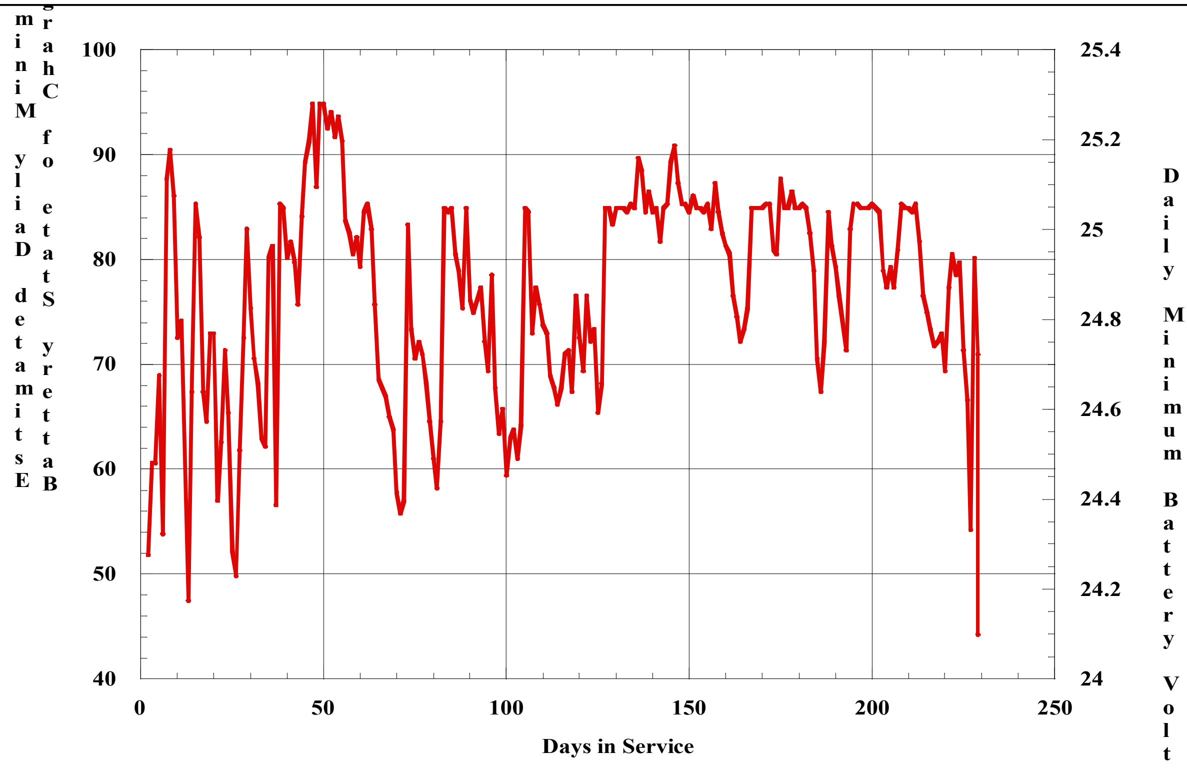


Figure 2. Typical Winter System Performance (February 12-15, 2000)



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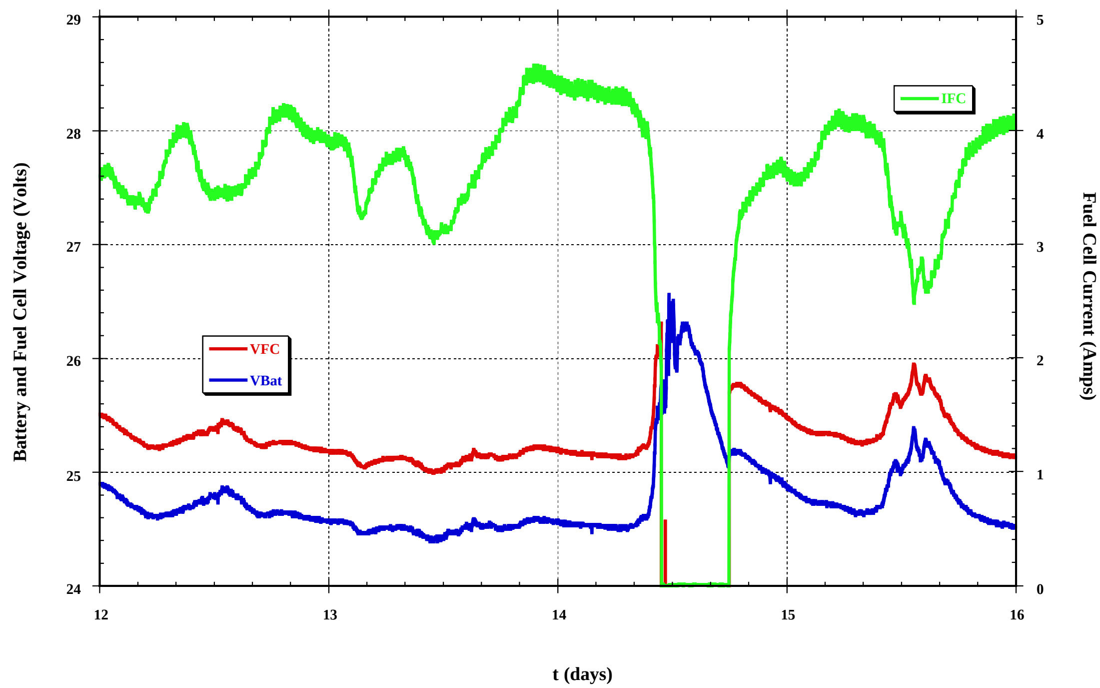

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