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Journal of Power Sources 153 (2006) 151–156
JOURNAL OF POWER SOURCES
www.elsevier.com/locate/jpowsour

Short communication

High efficiency fuel cell based uninterruptible power supply for digital equipment

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Received 11 January 2005; accepted 10 February 2005
Available online 24 June 2005

Abstract

Eliminating the ac–dc converter (such as a computer's power supply), in a dc system when using a fuel cell based uninterruptible power supply (UPS), serves several primary functions. Firstly, it eliminates the need for a dc–ac inverter, and secondly, it eliminates a usually highly inefficient component—the power supply. Multiple conversions result in multiple inefficiencies. By replacing the computer's ac power supply with a high efficiency dc power supply capable of operating directly from a fuel cell – and thereby eliminating the inverter – the overall efficiency of the UPS can be increased by 50% or more. This is essential considering that the primary function of a fuel cell based UPS is long-term operation of the system, and poor efficiency equates to higher fuel consumption. Furthermore, inefficient systems have greater power demands, and therefore a larger fuel cell stack is needed to power them. At the present cost of fuel cell systems, this is a considerable problem. The easiest way to accomplish a direct dc UPS is to replace the computer's ac–dc power supply with a dc–dc power supply.

Keywords: Fuel; Cell; Uninterruptible; Computer; Power; Supply

1. Introduction

Fuel cells are rapidly becoming a significant source of power in our society, and their use in a variety of applications is inevitable. One such application is the use of a fuel cell as the power source in an uninterruptible power supply (UPS), for use with digital equipment, such as a personal computer (PC). The primary purpose of using a fuel cell instead of a battery as the power source is the fuel cell's high energy density, and therefore, the ability to operate a system for very long periods of time during a utility grid failure. However, while a fuel cell can operate uninterrupted for very long periods of time, it is still limited by the amount of fuel (usually hydrogen) available. The few fuel cell based UPSs that have emerged, utilize a conventional dc–ac inverter in order to convert the fuel cell's dc power to ac power for use by the computer's power supply [1–3]. Thus, there are a *minimum* of two power conversions taking place between the fuel cell, and the computer's actual components—dc–ac in the inverter, and then ac–dc in the computer's power supply. This is a considerable waste of hydrogen resource for a fuel cell based UPS. Furthermore, if the inverter is incapable of accepting the wide input voltage that a fuel cell provides, an additional dc–dc converter must be used to bring the input voltage to within the inverter's tolerance, which results in three inefficiencies. Finally, computer power supplies are notoriously inefficient—typically 65% to 70% at full load. While this is tolerable for a grid operated PC, or when the only backup power required is for a short period of time, this is a significant loss when dealing with long-term operation using limited resources, i.e. a fuel cell system with limited fuel.

This work demonstrates a fuel cell based true online UPS in which the computer's ac power supply is replaced with a wide voltage input, high efficiency dc power supply, and thereby the inverter is eliminated as well. This resulted in a UPS with a substantially improved efficiency, and consequently, a significantly improved operating time [4]. As

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0378-7753/$ – see front matter © 2005 Published by Elsevier B.V.
doi:10.1016/j.jpowsour.2005.02.091

the use of alternative energy increases in society, the need to improve the efficiency of both the source *and* the load becomes more important.

2. Model development

This research work was begun by looking at developing an uninterruptible power supply that would use a dc computer power supply during backup mode, bypassing the computer's ac power supply. It would utilize an additional dc–dc converter in order to stabilize the fuel cell's output voltage prior to being fed into the dc power supply for the computer. It is essential to do this since the voltage of the fuel cell used in this experiment can range from 39 V (in open-circuit condition), down to 20 V (just before the short-circuit condition). In addition, a relay would be used for the transfer switch. This configuration is shown in Fig. 1.

This design had two inherent problems. First, it still had two conversions during the backup period, both of them dc–dc. While the efficiency would be better than using the computer's power supply, it was not as efficient as it could be. The second problem – a fatal one – was due to the transfer switch following the computer's power supply. This approach provided no "hold time" from either power supply during the transfer time. This meant the computer was without power for a few milliseconds (the relay's switching time), which would cause the computer to reboot. This defeated the primary purpose of a UPS, so this plan was dismissed.

2.1. Improved design

A better approach was to use a true online UPS design. This design typically uses a battery charger in parallel with a sealed lead-acid (SLA) battery, which is then connected into a dc–ac pure sine wave inverter; this provides power to the computer's ac power supply. It is also called a double-conversion UPS since the ac line voltage is converted to dc, and then converted back to ac. The benefit to this design is that there is literally a zero transfer time because the battery immediately picks up the load when the grid power fails. The other benefit is that the output power is conditioned through the process, and is free of spikes and sags.

In utilizing this design, the computer's ac power supply needed to be eliminated, and replaced with a wide input voltage, high efficiency dc power supply. Since a dc power supply with a sufficiently wide input voltage range was unavailable, a 200 W power supply was built using four dc–dc converters, +5 V, +12 V, −5 V and −12 V. A standard AT type computer was used instead of an ATX type since this was only a proof-of-concept, and it was a little easier to build the necessary power supply. A 12 V TFT LCD monitor was also used since it is more efficient, can be operated from a 12 V source without much modification, and it is becoming the trend for monitors. This monitor consumed a mere 28W of power, in contrast to the more than 100 W of power consumed by the 15″ CRT monitor that had been used previously. For long-term backup operating times, this is a sensible decision. This configuration is shown in Fig. 2.

The battery and charging unit were connected to the custom built dc power supply as shown in Fig. 2 above. When all components were turned on, the system worked perfectly.

2.2. Adding the fuel cell

The fuel cell now needed to be incorporated into the design. The initial plan was to use the fuel cell to charge the

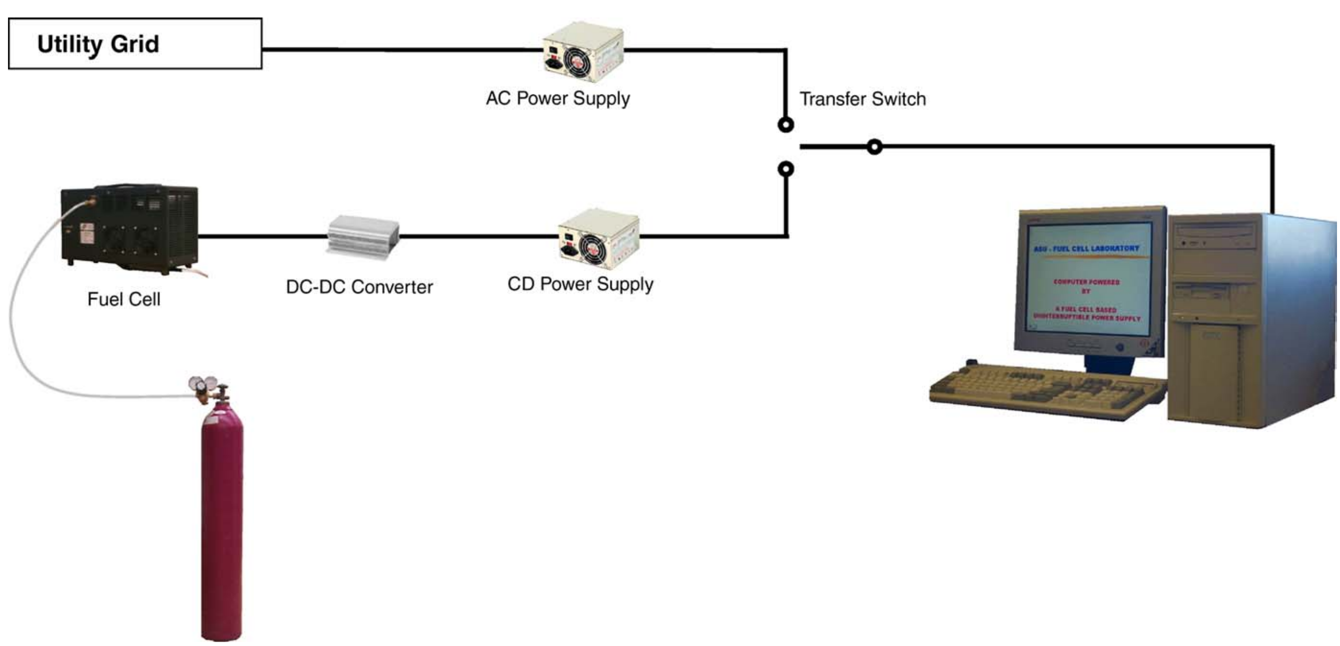

Fig. 1. Original planned design of fuel cell based UPS. *Note*: the computer's power supply is shown as separate from the computer.

Fig. 2. Redesigned UPS without fuel cell system incorporated.

battery as well as power the computer during backup time. However, in order to do this, it was necessary to isolate the fuel cell from the battery. Using a dc–dc charge controller could do this, but doing so would add to the overall cost of the UPS, as well as contribute a small power loss through the charge-controlling unit.

It was decided that since the battery would be fully charged when grid power failed – at which point the fuel cell would pick up the load – the benefit of trying to maintain a float charge on the battery from the fuel cell was not worth the cost to do so. Therefore, it was decided to incorporate the fuel cell into the system by connecting it directly to the computer's dc power supply. However, the battery needed to be maintained as a backup source in the event of sudden surge power demands, or if the fuel cell should fail for some reason, the battery would once again power the computer. If the fuel cell were directly connected in parallel with the battery to the load, the battery – being the lower voltage – would dictate the voltage of the system. This would keep the fuel cell operating at a lower voltage than it would operate at if the battery were removed from the system, thereby resulting in a lower efficiency for the fuel cell. Once again, this is not a desirable condition. It was finally decided to use a simple blocking diode between the battery and the fuel cell. This would allow the fuel cell to directly power the computer with the support of the battery, but would isolate the fuel cell from the battery, and therefore the battery would not affect the fuel cell's voltage output. The final configuration is shown in Fig. 3.

A transfer switch is unnecessary in this design since the fuel cell provides the higher voltage, therefore, it will pick up the load automatically as soon as it is applied to the load. This was confirmed through measurements showing the battery had zero current flowing to the computer's power supply when the fuel cell system was powering the computer. However, an exception to this occurs when the fuel cell's voltage is lower than the battery's voltage. In this event, the battery will not only provide the entire power to the load, but it will actually feed some current *to* the fuel cell as well. This occurs if the fuel cell's membrane is dehydrated, and the output voltage of the stack is lower than the battery's voltage. A remedy for this problem is to turn on the fuel cell under a resistive load until the MEAs are rehydrated, and the voltage is acceptable. A relay could be used to keep the fuel cell disconnected from the load during this time. When the voltage is determined to be within acceptable tolerance, the relay would then connect the fuel cell to the load. Obviously, the system would be

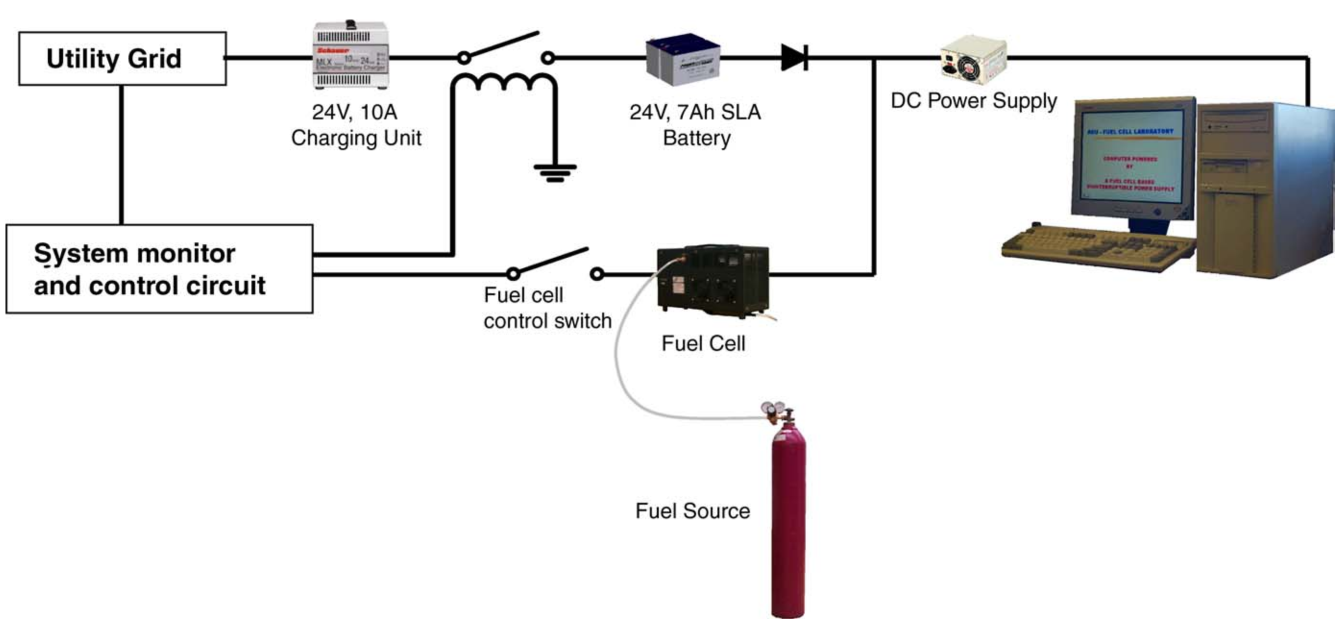

Fig. 3. Final UPS layout.

operating from the battery during this rehydration process. An alternative is to maintain the fuel cell in a standby state (with hydrogen applied to the stack), perhaps using the available power to trickle charge the battery. The primary problem with this method is that a UPS may not be utilized for a long period of time; therefore, the user may find considerably less hydrogen available for the UPS when it is actually needed. Furthermore, leaving the fuel cell operating at very low current for extended periods of time will result in a reduction of available power due to collecting of the platinum particles on the fuel cell's electrodes.

It should be noted that there was a 385 μA current flowing from the battery through the charging unit; this is normal, and was stopped by simply disconnecting the charging unit from the battery with a relay. This also allowed the charging unit to be disconnected in the event of a utility grid undervoltage condition. This is of much greater concern since an undervoltage condition will cause the input current to increase since the output power remains constant. If the voltage drops too low, the transformer of the charger can overheat due to the higher input current.

2.3. *The system monitoring unit*

Finally, a controlling circuit was incorporated to monitor the system, and turn on – or turn off – components as necessary. A overvoltage/undervoltage relay was used for the line-voltage monitoring. One of the pins of the microcontroller was tied high, and one of the relay's pins was tied to ground. When a power fault condition was detected, the relay would trip, and shunt the microcontroller's detecting input pin to ground. After appropriate time delays and retesting of the utility power, it disconnected the charging unit, turned on the fuel cell, and then proceeded to continuously check for the line-voltage to be restored. Using a microcontroller as the controlling unit allows a change of time delays, and the order of relay switching with very little effort. Latching relays were used so as to eliminate the need to maintain power to the relays' coils.

An additional function for the microcontroller would be to monitor the fuel cell's output voltage, and if the voltage is low, connect the fuel cell through a power resistor allowing the fuel cell to rehydrate as mentioned above. When the voltage is within parameters, then connect the fuel cell to the load.

3. Results and discussion

The system was tested to determine whether the expected improvement in performance was attained. Measurements had been taken using a standard fuel cell powered UPS with a dc–dc converter, an inverter, and the computer's power supply. The power consumed by this system was:

$$3.09\,\text{A} \times 33.7\,\text{V} = 104.1\,\text{W} \quad (1)$$

The computer was then operated from the fuel cell powered UPS without the inverter, and the measured results were:

$$1.89\,\text{A} \times 34.3\,\text{V} = 64.8\,\text{W} \quad (2)$$

This is a power consumption reduction of:

$$\frac{104.1 - 64.8}{104.1} \times 100 = 37.8\% \quad (3)$$

and results in an operating time improvement of:

$$\frac{104.1 - 64.8}{104.1} \times 100 = 60.6\% \quad (4)$$

The operating time for the system using a standard fuel cell powered UPS with a K/UK type hydrogen cylinder was approximately 120 h. Using the same cylinder at the improved efficiency would result in:

$$120\,\text{h} \times 1.606 = 192.7\,\text{h} \quad (5)$$

This is a significant improvement from the standard UPS operating time of 120 h.

It should also be noted that the conventional UPS required 104.1 W, while the direct dc UPS required only 64.8 W. This means a 300 W fuel cell system could easily power three to four of the high efficiency computers, instead of only two using the conventional UPS. This would result in a lower up-front fuel cell cost as well.

Finally, if a CRT monitor had been used in the initial evaluation, the power requirement would have been approximately 180 W instead of 104.1 W for the conventional UPS, and the initial operating time at the beginning of the testing would have been reduced to approximately 70 h, instead of 120 h. Of course, the relationship of the monitor's power demands to the computer's power demands will not always be as significant as this, but it should be a serious consideration for anybody interested in long-term operation of a system using expensive hydrogen fuel.

3.1. *System operation analysis*

Clearly, when a UPS is intended to operate a computer for extended periods of time, it is essential to replace the computer's inefficient power supply with a high efficiency dc power supply. This approach is simple to implement if:

(1) The UPS is an online UPS since it is already providing dc power.
(2) It is a typical PC since the power supply is easily replaced.

This simple approach would allow even a battery-powered UPS to operate 60.6% longer than it would operate using the same battery bank with a conventional UPS. For short-term operation (<2 h) a standard inverter based UPS would be sufficient, but for operating times of several hundred hours (or days), the battery costs start to become significant, and the battery space requirements become considerable.

Incorporating the fuel cell into the system makes it more challenging than just a battery-powered UPS since the fuel cell will be working in parallel with the battery, and each has its own voltage. If the fuel cell's voltage drops below the battery's voltage at any time, the battery will automatically pick up the entire load, and this is not desirable. Using a blocking diode results in the higher voltage component being the primary power source. Once the fuel cell is operating at full voltage, the battery can be disconnected, but then the battery is no longer available for sudden surge demands. This would be a problem if such a demand occurred.

The fuel cell voltage will not drop below the battery's voltage (unless the fuel cell's MEAs are dehydrated as discussed above), since as soon as the load is large enough to cause the fuel cell's voltage to drop below the battery's, the battery will pick up the load, and thus, reduce the demand on the fuel cell allowing its voltage to recover. Instead, if the fuel cell's voltage drops to the battery's voltage, the fuel cell and the battery will find equilibrium, and share the load. However, with proper planning of the fuel cell system's size with respect to the load, this should rarely – if ever – occur.

3.2. Future improvements

There is a need to provide a means of rehydrating the fuel cell before applying it to the load. This could best be accomplished by providing a resistive load through which the fuel cell can discharge for a few minutes until it is sufficiently rehydrated, and up to acceptable voltage (a fuel cell produces water as it operates, so it rehydrates automatically). The basic configuration of the rehydrating system is shown in Fig. 4 below.

There should also be a voltage monitoring circuit measuring the voltage across the temporary resistive load in order to switch the fuel cell over to the computer system when the voltage is sufficient. This is a better approach than allowing the fuel cell to operate continuously with a small load applied to it due to the gradual reduction of fuel, and platinum particle grouping.

Additional improvements would be minor changes to improve efficiency, or reduce system size. The computer's power supply could be more closely matched to the computer's power needs, thus improving its efficiency. However, this will only improve the overall efficiency a minimal amount, and might result in the computer's demand exceeding the power supply's capability on occasion.

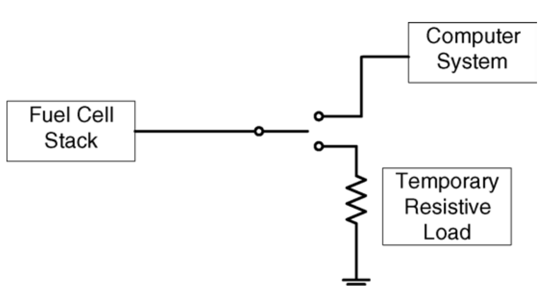

Fig. 4. Basic configuration for fuel cell rehydration.

Presently, the 24 V battery powers the system monitoring and control unit while in backup mode (otherwise it is powered by the grid). The fuel cell could power the unit when in backup mode, which would not only extend the battery life, but would allow either the fuel cell *or* the battery to be available to power it, thus creating a more secure redundant power condition. It should be noted that the power consumption of the controlling circuit is only about 8.5 mW during the quiescent period, which equates to a current of only about 354.2 μA (based on the 24 V nominal supply voltage), and it would take more than two years to discharge the 7Ah battery used in this system. This length of backup would most likely never occur, but if it did, additional batteries could be added for continued operation, or hot-swap batteries could be employed.

4. Conclusions

The primary restraint on a fuel cell based UPS today is cost, since fuel cell systems are still quite expensive. However, that is expected to improve as fuel cell technology improves, and production volume of fuel cell stacks increase. Fuel cell technology is effectively in its infancy, so there is considerable potential for the further development of this "new" technology.

As the popularity of the fuel cell grows, the ability to operate mission critical systems for extended periods of time, or large systems for a short period of time will also grow. It will become essential for a UPS to provide a quality input signal, as well as provide long-term operation with the minimum amount of peripheral equipment. In order to attain this goal, the system must be as efficient as possible to reduce Hydrogen consumption.

This research demonstrated a method to increase the operating time of a computer system by replacing the computer's poor quality power supply with a high efficiency dc power supply, which also allowed the removal of the dc–ac inverter.

A considerable amount of effort has gone into improving the efficiency of the fuel cell, but it is counterproductive to improve the fuel cell's efficiency, while neglecting the load and any interfacing equipment the fuel cell is powering. It has been demonstrated that the load can contribute significantly to a system's overall performance. This is particularly important when working with alternative energy technologies—such as a fuel cell.

Acknowledgments

We would like to express our appreciation for the support of Arizona State University, and for the funding provided by Arizona State University through its faculty-grant-in-aid (FGIA) program. This project was carried out using a fuel cell stack generously donated by Arizona Public Service (Timothy McDonald).

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