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Fuel Cell | Storage Battery | DC System

Backup Power Supply System Using Fuel Cells as Disaster Countermeasure for Radio Base Stations

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The Great East Japan Earthquake of 2011 underscored the need for telecommunication facilities equipped with a long-term backup power supply. Present backup power supply systems make use of lead storage batteries, but achieving a storage capacity that can provide long-term backup requires excessively large and heavy batteries that can make installation difficult. We have constructed a prototype backup power supply system for anti-disaster purposes using power-generating fuel cells and storage batteries such as lithium-ion batteries, and have performed tests to examine system operation and optimal operating methods. This article presents the results of these tests.

1. Introduction

The disastrous effects of the Great East Japan Earthquake of 2011 emphasized the need for a telecommunication infrastructure that could deliver power even during disasters, and at NTT DOCOMO, the development of environmentally friendly, disaster-resistant green base stations [1]–[4] is underway. There is a growing need, in particular, for telecommunication facilities equipped with a long-term backup power supply that can continue to provide services for an extended period of time during disaster-related power outages. Present backup power supplies make use of lead storage batteries, but using batteries of this type to achieve a storage capacity that can provide long-term backup (of about 24 hours) requires an excessively large and heavy configuration that can make installation difficult. In response to this problem, we constructed a power supply system for radio base stations using high-energy-density fuel cells*1 as a backup power supply. In this article, we propose optimal control and operation methods for a backup power supply combining fuel cells and a storage battery, and present and discuss test results.

2. Overview of Fuel Cell System

We first give an overview of a fuel cell system to be applied as a backup power supply and describe a test environment for simulating telecommunication facilities using this fuel cell system.

The type of fuel cell used here is a Polymer Electrolyte Fuel Cell (PEFC)*2 that uses a methanol water solution as fuel and that generates electric power by reforming the methanol water into hydrogen

*1 **Fuel cells**: Cells that generates electricity through a chemical reaction between hydrogen and oxygen.
*2 **PEFC**: A fuel cell that generates electricity by supplying an oxidant to a cathode and a reductant (fuel) to an anode on either side of an ion exchange membrane.

using a reformer*3. Specifications for this fuel cell are listed in **Table 1**.

As shown in **Figure 1**, the test environment consist of a rectifier*4, storage battery, DC electronic load equipment and two fuel cells. Here, the rectifier consists of three 50 A units connected in parallel while the storage-battery block consists of four 12 V lead storage batteries connected in series. The load equipment is achieved using DC electronic load equipment (1–5 kW). The rectifier inputs 3-phase 200 V*5 alternating current and outputs 53.5 V direct current. An external view of the fuel-cell equipment is shown in **Figure 2**.

3. Startup and Shutdown Tests

We here report the results of tests that we performed in the test environment described above to examine the electrical characteristics of fuel-cell startup and shutdown. Fuel-cell parameters in this test were set as follows:

- Fuel-cell startup voltage: 51 V
- Fuel-cell output voltage : 52 V

In other words, the fuel cell starts up when the voltage supplied to the load drops below 51 V. The system then supplies a voltage of 52 V from the fuel cell.

Voltage fluctuation associated with power outage and power restoration for a 1 kW load is shown in **Figure 3**. For the case of a 1 kW load, storage-battery voltage drops as far as 48 V after the occurrence of a power outage due to a voltage drop in internal resistance. The fuel cell detects this voltage drop and begins to start up approximately one minute after the start of the power outage. At this point, the voltage drop in the storage battery begins to ease and the fuel cell gradually increases output so that voltage rises. Once the voltage approaches the fuel-cell output of 52 V, the fuel cell begins to operate stably. Later, when power is restored, the voltage returns to the rectifier voltage of 53.5 V and the fuel cell enters a standby state in preparation for the next power-outage incident.

Table 1 Fuel-cell specifications

	Specifications
Output power	4.5 kW
Output voltage	–48 V DC (46 - 56 V DC)
Output current	104 A (max. 125 A)
Fuel	Special-purpose methanol (built-in 225 ℓ tank)
Temperature range	–5 - 46 °C
Dimensions	130 × 110 × 177 cm
Weight	488 kg (including 193 kg fuel)

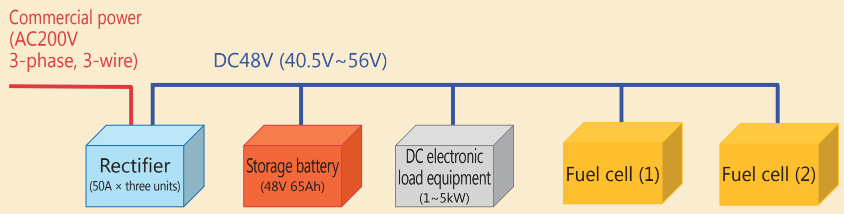

Figure 1 System configuration in test environment

Figure 2 External view of fuel-cell equipment

*3 **Reformer**: A device for generating a chemical reaction to extract hydrogen from methanol.

*4 **Rectifier**: A device for converting AC power to DC power.

*5 **3-phase 200 V**: AC power supply for supplying motive power; a power supply with three 200 V alternating currents with different phases separated by 120 degrees.

4. Optimization of Output Voltage

When power is restored after a power outage and power from the rectifier is once again output, the rectifier voltage becomes higher than that of the fuel cell, and as a result, output from the fuel cell begins to drop. The type of fuel cell used in this experimental equipment stops generating power when its output drops below 300 W. The condition for fuel-cell output to drop below 300 W is as follows. The drop in voltage (voltage drop A) due to output current on the load from the rectifier's output voltage is compared with the drop in voltage (voltage drop B) given a fuel-cell output of 300 W. The condition is met if the voltage on the rectifier side becomes higher taking into account the amount of voltage drop on either side. A power system chart depicting this condition is shown in **Figure 4**.

Fuel-cell halt condition:
rectifier output voltage − voltage drop A
> fuel-cell output voltage − voltage drop B

If fuel-cell output voltage takes on a value that satisfies this condition, the fuel cell halts operation as power is restored. In actuality, however, the time required for shutting down the fuel cell at power restoration can be shortened and fuel consumption reduced for an output voltage 0.7 V less than the maximum value of output voltage satisfying this condition (output-voltage limit). The relation between the difference between output-voltage limit and output voltage and halt time is shown in **Table 2**. As shown, halt time shortens as the difference between output-voltage limit and output voltage increases. If this voltage difference becomes as large as 0.7 V, halt time shortens to about 100 s at the time of power restoration. However, to minimize the overall width of voltage fluctuation, it is preferable that fuel-cell output voltage be as close to rectifier voltage as possible. For this reason, a voltage value 0.7 V lower than the output-voltage limit is taken to be the recommended fuel-cell output voltage here.

5. Selecting Capacity of Storage Battery (internal resistance)

Although the fuel cell starts up automatically at the time of a power outage, the time that is actually required to begin supplying power to the load is 1–2 min. As a result, there is a need for an auxiliary backup power supply consisting of

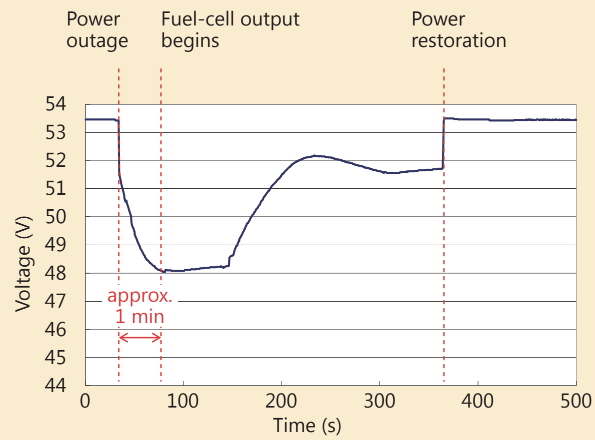

Figure 3 Voltage fluctuation in power outage/restoration for a 1 kW load

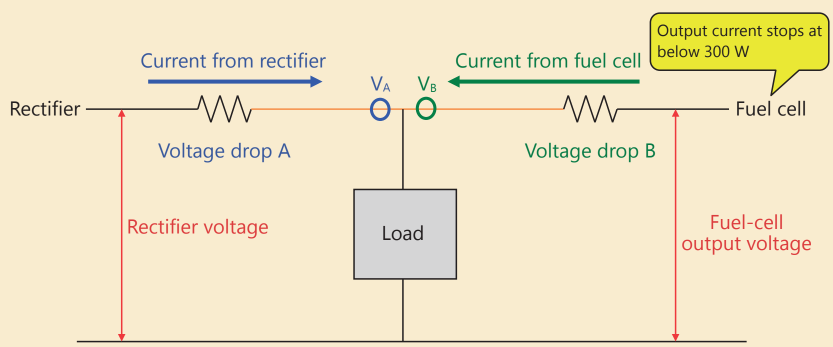

Figure 4 Output system diagram

a lead or lithium-ion storage battery to provide power during this startup time. In the following, we describe a technique for determining how much storage capacity is needed in such an auxiliary backup power supply.

To prevent over-discharging of a storage battery connected to a rectifier, the rectifier is equipped with a shutdown switch to prevent battery voltage from dropping below 41 V. Discharge voltage of a discharging storage battery includes a voltage drop associated with discharge current and the internal resistance of the battery. This voltage drop due to the battery's internal resistance increases in a nearly proportional manner to the discharge current. The relation between discharge current and voltage drop for the case of four 12 V lead storage batteries connected in series is shown in **Figure 5**. A voltage drop of approximately 3.5 V occurs for a discharge current of 80 A. Since the lead storage battery used here is of the 65 Ah type, a discharge current of 80 A results in a discharge rate of approximately 1.2 C. Accordingly, a voltage drop of approximately 3.0 V would occur for a 1 C discharge*6. The capacity of a backup storage battery for use during power outages can be made small by installing a fuel cell, but using a storage battery with a small capacity results in a high discharge rate for the same discharge current and a large voltage drop as a result. It is therefore necessary to select a storage-battery capacity such that the voltage does not drop below 41 V due to the battery's internal-resistance voltage drop at maximum usage current.

Table 2 Relation between voltage difference with fuel-cell output voltage limit and halt time

Voltage difference with output voltage limit	Halt time from power restoration
0.1 V	514 s
0.2 V	290 s
0.3 V	262 s
0.4 V	221 s
0.5 V	206 s
0.6 V	196 s
0.7 V	101 s
0.8 V	98 s
0.9 V	97 s
1.0 V	92 s

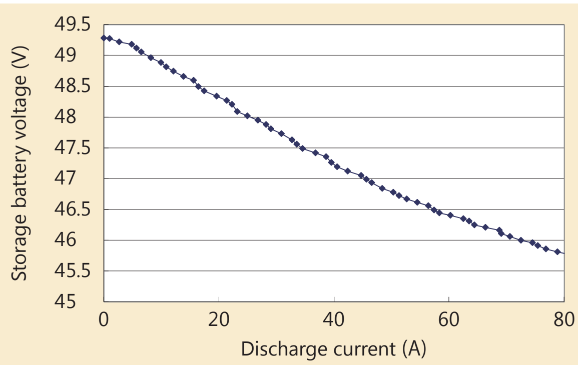

Figure 5 Relation between discharge current and voltage drop (four 12V lead storage batteries connected in series)

6. Adjusting Output Voltage During Parallel Operation

When connecting and operating multiple fuel cells in parallel, it is preferable that fuel consumption be uniform across all fuel cells. If fuel consumption is unbalanced, the supplied power will become insufficient when the fuel of one fuel cell is depleted. However, even if the output voltage of each fuel cell is made the same, a difference in wiring length (wiring resistance) can result in unbalanced fuel consumption. We explain this phenomenon referring to **Figure 6**. Given that fuel cell (1) and fuel cell (2) are connected in parallel, if wiring resistance R_1 and wiring resistance R_2 from the branching point differ, a higher amount of power will be consumed from the side with the smaller resistance creating an imbalance in fuel

*6 **1 C discharge**: The discharge rate whereby a fully charged storage battery completely discharges in 1 h. A complete discharge over 2 h and one over 30 min corresponds to 0.5 C and 2 C, respectively.

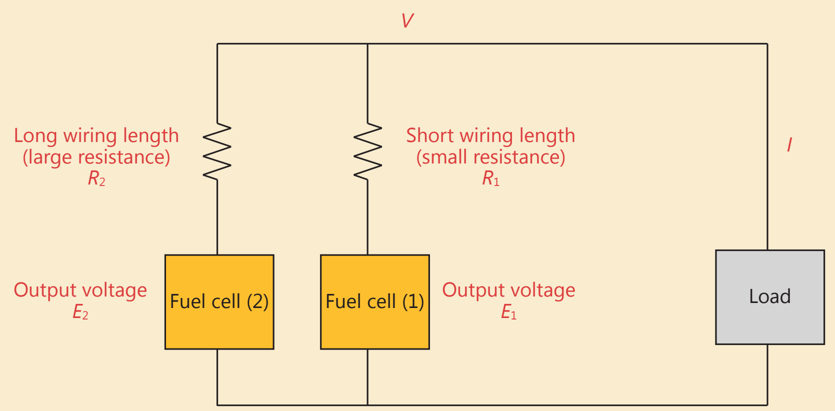

Figure 6 Relation between difference in wiring resistance and power consumption.

For the test environment described in this article, R_1 and R_2 are approximately 0.005 Ω and 0.008 Ω, respectively, which results in a fuel consumption (fuel-cell-1:fuel-cell-2) of approximately 8:5. To make this unbalanced fuel consumption uniform, the output voltage of each fuel cell must be slightly adjusted. The following presents equations for making fuel consumption uniform when operating two fuel cells in parallel. Here, I is usage current and V is voltage at the branching point of fuel cells connected in parallel.

$$V = E_1 - \frac{I}{2} R_1 \quad (1)$$

$$R_1E_1 - R_2E_2 = (R_1 - R_2)V \quad (2)$$

Calculating output voltages E_1 and E_2 that satisfy these equations and setting each fuel cell accordingly makes fuel consumption nearly uniform. For the test environment of this article, E_1 is 51.00 V and E_2 is 51.12 V.

The equations to be used when connecting multiple fuel cells (N units) in parallel are given below. Here, the ith output voltage can be calculated from output voltage E_1 of the 1st unit.

$$V = E_1 - \frac{I}{N} R_1 \quad (3)$$

$$R_1E_1 - R_iE_i = (R_1 - R_i)V \quad (4)$$

Calculating output voltage E_i of each fuel cell that satisfies these equations and setting each fuel cell accordingly makes fuel consumption nearly uniform.

7. Configuring an Optimal Backup Power Supply System

In this article, we described the testing of a backup power supply system combining a storage battery and fuel cells and examined fuel-cell halting voltage, storage-battery capacity and voltage adjustment under parallel operation as guidelines for optimally configuring equipment and making settings. In the actual deployment of fuel cells, power supply facilities must be designed and fuel cells configured taking all of the above into account.

Recommended parameter settings when deploying a single fuel cell in present mobile base stations are listed in **Table 3** for reference purposes. Since rectifier voltage depends on the type of storage battery used (set of 23 long-life, stationary sealed lead-acid storage batteries, set of 24 long-life, stationary sealed lead-acid storage batteries, or set of four 12 V, compact valve-regulated lead-acid storage batteries), fuel-cell settings likewise depend on the storage battery. We first consider the condition for halting fuel-cell operation, and if we allow for voltage drop, it is desirable that fuel-cell output voltage be set to a value 1–1.5 V lower than the rectifier voltage. Next, separate fuel-cell startup voltages can be set according to power-generation stack*7 1 and power-generation stack 2. In the event that the supply of power to the load is insufficient by stack 1, stack 2 can be started up. Setting the fuel-cell startup voltage to a value 1–2 V less than the rectifier voltage presents no issues; the values listed in Table 3 are provided for reference.

We note here that the rectifier is equipped with a function for assessing storage-battery deterioration. This func-

*7 **Power-generation stack**: The portion of a fuel cell that generates electric power by supplying hydrogen to a fuel electrode and oxygen to an air electrode to produce an electrochemical reaction.

Table 3 Fuel-cell reference parameters

	Set of 23 long-life, stationary sealed lead-acid storage batteries	Set of 24 long-life, stationary sealed lead-acid storage batteries	Set of four 12 V, compact valve-regulated lead-acid storage batteries
Rectifier voltage	51.3 V	53.5 V	54.6 V
Fuel-cell output voltage	50.0 V	52.0 V	53.0 V
Fuel-cell startup voltage (1)	49.0 V	51.0 V	52.0 V
Fuel-cell startup voltage (2)	48.0 V	50.0 V	51.0 V

tion can be used to periodically lower rectifier voltage and automatically assess whether the storage battery is deteriorating. When using this function, it must be kept in mind that the fuel cell will automatically start up when lowering the rectifier voltage. It is therefore desirable that the fuel-cell startup voltage be set lower than the rectifier voltage at the time of storage-battery deterioration assessment and that the fuel cell be started up by the rectifier's power-outage signal. This can be achieved by connecting the contact point of the power-outage signal on the rectifier with the contact point of the remote start switch on the fuel cell.

8. Conclusion

With the aim of constructing a backup fuel cell system for radio base stations, this article presented optimal operating conditions and design policies required for system design and operation.

The fuel cell used here features a volume and weight approximately one-half and one-fourteenth, respectively, that of a conventional lead storage battery and shows promise as a next-generation long-term backup power supply for radio base stations. Looking forward, combining such fuel cells with compact lithium-ion batteries should result in an even more compact and space-saving configuration.

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