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Analysis of DMFC/battery hybrid power system for portable applications

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Abstract

This study was carried out to develop a direct methanol fuel cell (DMFC)/battery hybrid power system used in portable applications. For a portable power system, the DMFC was applied for the main power source at average load and the battery was applied for auxiliary power at overload.

Load share characteristics of hybrid power source were analyzed by computational simulation. The connection apparatus between the DMFC and the battery was set and investigated in the real system. Voltages and currents of the load, the battery and the DMFC were measured according to fuel, air and load changes. The relationship between load share characteristic and battery capacity was surveyed. The relationship was also studied in abnormal operation. A DMFC stack was manufactured for this experiment. For the study of the connection characteristics to the fuel cell Pb-acid, Ni–Cd and Ni–MH batteries were tested.

The results of this study can be applied to design the interface module of the fuel cell/battery hybrid system and to determine the design requirement in the fuel cell stack for portable applications.

Keywords: Direct methanol fuel cell; Hybrid; Battery

1. Introduction

Direct methanol fuel cell (DMFC) generates electricity from the reaction of methanol and oxygen in air. The DMFC has many merits compared with other types as fuel cell as follows; no need of fuel reformer, easy to transport, low price, uses liquid fuel such as methanol, safer reaction temperature (lower then 100 °C). Therefore, the DMFC is a very advantageous power source for mobile, residential, small and remote discrete demand as well as for hybrid electric vehicles [1].

In this study, a DMFC/battery hybrid power system using a 40 W DMFC stack was manufactured. The dynamic characteristics were tested as a function of to the fuel cell and battery load share in a portable hybrid power source [2,3]. A battery was connected as an auxiliary power source, and the characteristics of charge or discharge were analyzed. Additionally, theoretical work was carried out by simulation.

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2. Experimental

2.1. DMFC stack

For this experiment, we manufactured a 40 W DMFC stack with an external manifold [4]. This stack is shown in Fig. 1. The stack comprises six cells with size 6.2 cm × 16 cm × 15 cm, of which the electrode area is 129 cm^2 (12.5 cm × 10.3 cm). The structure was built in such a way that fuel, air and oxygen are supplied to an external manifold and taken into the stack.

To use the DMFC as a portable power source, its voltage and current characteristics were measured. Fig. 2 shows how the voltage–current characteristics of the 40 W DMFC stack change under changing temperature.

In this configuration, 2 M methanol was fed to the anode at 80 ml/min and air to the cathode at 10 l/min. The performance of the stack was 25 and 41 W at 30 and 65 °C, respectively.

2.2. Theoretical analysis of the hybrid power system

To use a fuel cell as a portable power system, it is recommended that power should be supplied by operation through

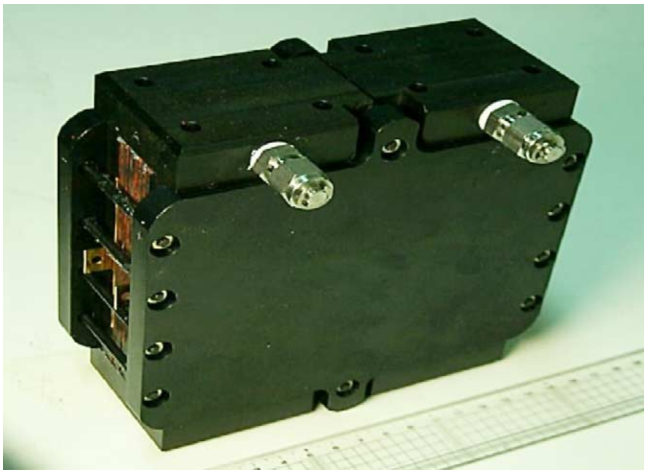

Fig. 1. Forty watt direct methanol fuel cell (DMFC) stack with external manifold type (anode, cathode: 5 mg PtRu/Pt (cm^2), MEA, Membrane: Nafion 115).

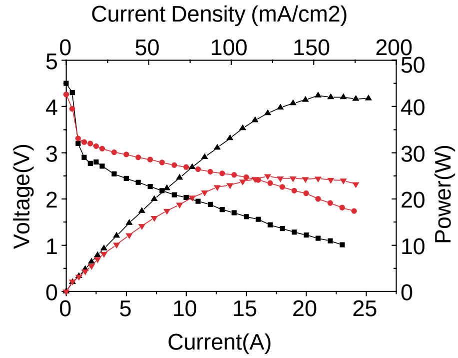

Fig. 2. Voltage–current characteristics change under changing temperature (CH_3OH: 2 M, 80 ml/min, air: 4 l/min, temp: 30 and 65 °C).

a linkage between a fuel cell and a battery. To provide theoretical analysis, we configured a hybrid power system using the DMFC as the primary power source and a battery as the secondary power source [5,6]. To analyze the load-sharing characteristics of the fuel cell and the battery, we interpreted a system, which provides a series connection between the fuel cell and the battery, through simulation. In this analysis, we reviewed the system characteristics in case of lack of booster, based on the simulation circuit designed to use the booster to control voltage fluctuation ratio.

Fig. 3a is a program for interpreting the theoretical dynamic characteristics of a fuel cell and battery hybrid system. The results of the interpretation are shown in Fig. 3b. This figure shows that load change under rapid power increase

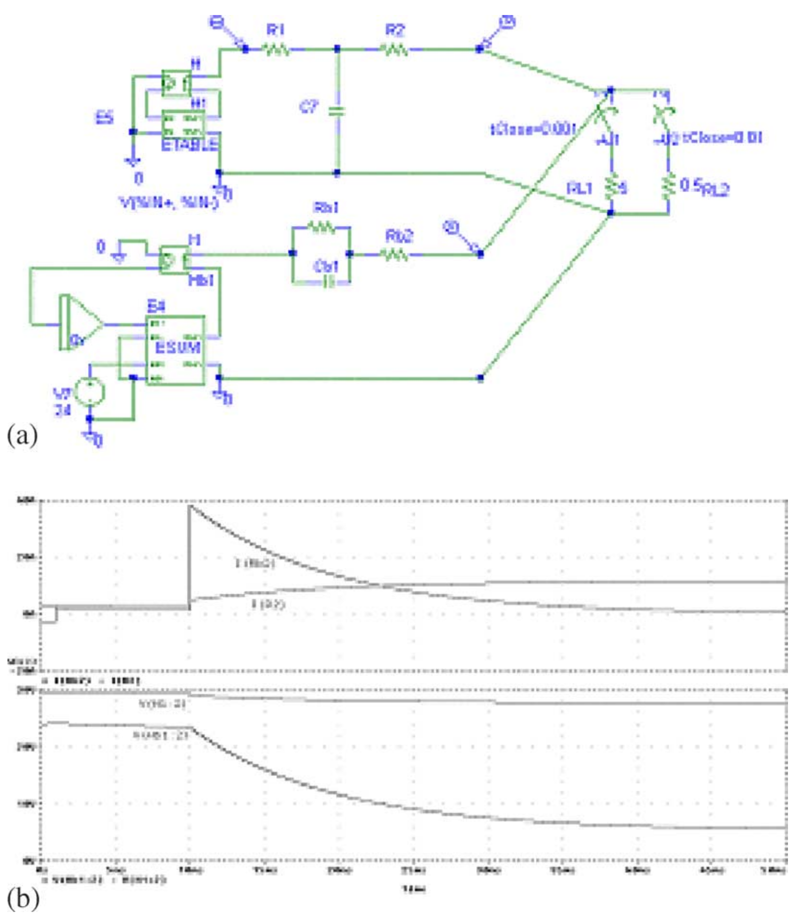

Fig. 3. (a) Program for interpreting the theoretical dynamic characteristic of a fuel cell and battery hybrid system. (b). Results of interpretation.

raises the battery current, forcing the battery to cover a large portion of the required power, and that the fuel cell covers the majority of required power in normal status. In response to a rapid increase of external load, a fast load-following battery supplied the portion of the power exceeding the fuel cell's supply capacity.

2.3. Hybrid power system

In the fuel cell and battery hybrid power system, an increase in the fuel supplied to fuel cell can ensure that there is enough fuel for providing the power needed by the external load. When the external load shows, however, a sudden change, the fuel cannot be fed fast enough to the fuel cell. This reduces the output voltage, and prevents the supply of enough power to the external load. This kind of system adopts a battery for protecting the fuel cell in order to prevent excessive use of the fuel cell and to feed power smoothly to the external load [7]. Therefore, we made a hybrid power system in parallel in order to analyze the load-sharing characteristics of the fuel cell and battery hybrid power system.

Based on theoretical observations, we carried out a connection experiment similar to the actual one by implementing a device connecting the fuel cell and the battery. In the experiment, we examined the load-sharing characteristics of the system by measuring the voltage and the current of the fuel cell, battery and load under changing current conditions. We interpreted the dynamic performance characteristics of the fuel cell and battery under a sudden load change, and investigated the load-sharing pattern, and predicted the basic specs required for a portable power system.

In the system to be used for the experiment on the connection between the fuel cell and the battery, the fuel cell has series connection with its protection circuit, and parallel connection with the battery. The fuel cell in the system is configured to output a constant power at all times, except when the load value shows a sudden rise.

The hybrid fuel cell and battery system is more effective when the external load exceeds the fuel cell's power output. In other words, the system can supply power using the supplementary power stored in the battery when the external load exceeds the power output of fuel cell system.

Fig. 4 shows a diagram of the connection device experiment for the fuel cell and battery hybrid power source. We experimented with the DMFC using a lead–acid battery, Ni–Cd battery and Ni–MH battery to constitute the hybrid system. Several batteries were connected in series or in parallel the fit to capacity of the fuel cell. Table 1 shows the types and specifications of battery used in the experiment.

2.4. Results and discussion

The fuel cell has an *I–V* characteristic in which the current change caused by a load change increases or decreases the voltage in inverse proportion to the current. In other words, a load change causes a change in the output voltage. To keep the constant voltage needed by a battery as supplementary power supply and load, therefore, a voltage controller is necessary [8]. In this experiment, however, was no installed. The experiment was done in the range 1.2–2.5 V, which is the available voltage of the fuel cell used. Also, the initial SOC (state-of-charge) of all the batteries used in the experiment was set to be over 95%.

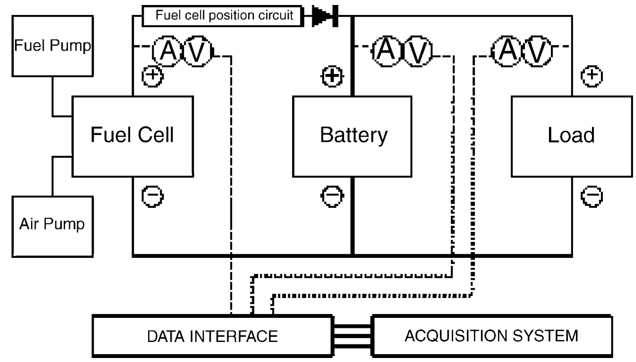

Fig. 4. Diagram of connection experiment device for fuel cell and battery hybrid power source.

Understanding the load-sharing characteristics of the hybrid fuel cell and battery power system is the most important core technology, of which the ultimate goal is to control the fuel used. An experiment investigating the results of a of a load change, on the system characteristics depending on the capacity and kind of battery was performed. To understand the dynamic characteristics of the fuel cell power system, we examined how much power is shared by the battery and the fuel cell under an instantaneous load change.

Generally speaking, in the hybrid fuel cell and battery system, the fuel cell plays the role of main power supply taking the majority of the load under normal conditions status, and the battery provides the rest of the power when overload is necessary. To this end, the fuel cell needs to have a higher electric potential than the battery. Otherwise, the fuel cell becomes a supplementary power supply and the battery serves as the primary power supply.

Fig. 5 shows the change of current and power depending on the load current in the fuel cell and battery hybrid power source, i.e. after setting the hybrid system to normal status. As shown in the figure, a load increase the battery gradually and raises output current progressively.

Table 1
Types and specifications of battery used in the experiment

Type of battery	Specification
Pb battery	2 V, 37 Ah
Ni–Cd battery	2.4 V, 10 Ah, 2.4 V, 5 Ah, 2.4 V, 1.2 Ah, 1.2 V, 5 Ah
Ni–MH battery	2.4 V, 2 Ah, 1.2 V, 4 Ah

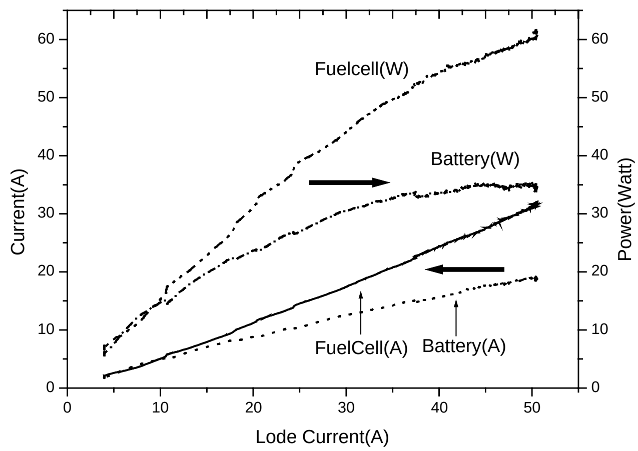

Fig. 5. Changes of current and power depend on the load current in the fuel cell and battery hybrid power source (CH_3OH: 2 M, 80 ml/min, air: 4 l/min, temp: 65 °C).

The experiment proves that load rise keeps the current from the battery higher than that from the fuel cell over time.

In the fuel cell/battery hybrid system, there is no booster for constant voltage control, and the battery is continuously discharged.

According to the experimental results using the Ni–Cd battery the discharge characteristic of a fuel cell and battery hybrid system is shown in Fig. 6 (for the case of lack of a booster). The discharge capacity of the battery decreased fast in the range of about 10% SOC (point A), and in the range of low than 5% SOC (point B), there was almost no discharging of the battery. This means that the battery is not completely providing power itself, although the load power is increased.

When the load decreases suddenly, the charging phenomenon in the battery was observed (point C). But when the load increases again, only an impulse response was observed (point D).

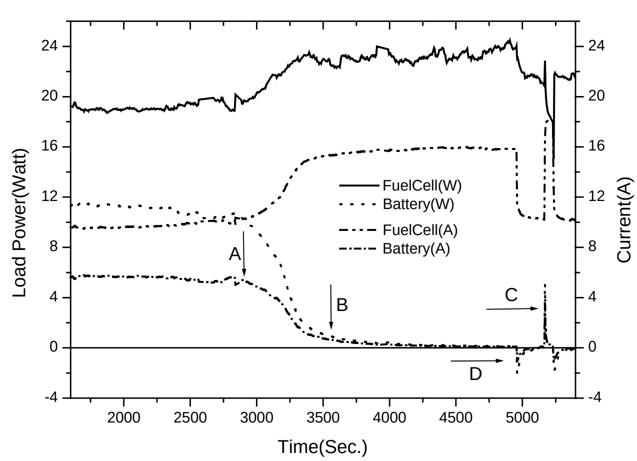

Fig. 6. Battery discharge characteristic of a fuel cell and battery hybrid system (DMFC and Ni–Cd battery, in case of lack of booster).

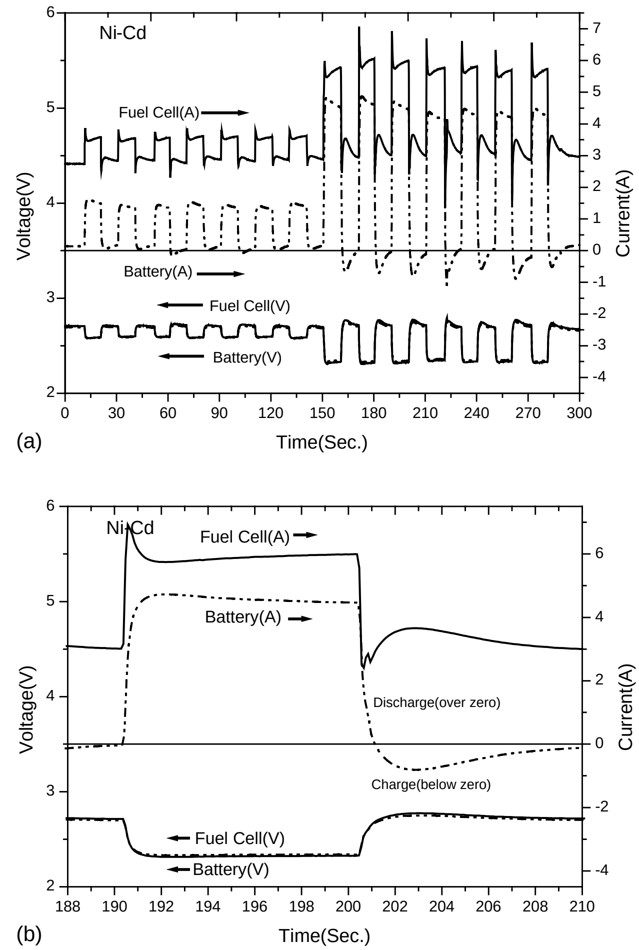

Fig. 7. (a) Constantly pulsed load characteristics of DMFC and Ni–Cd battery hybrid power source. (b) Typical transient current response on the application of a voltage interrupt (Ni–Cd 2.4 V, 5 Ah).

Therefore, the use of battery in the hybrid system for, is not related to the load power. Rather it is necessary to have an output voltage control booster to cover more then 20% of the normal voltage of the battery.

Fig. 7a shows the constantly pulsed load characteristics of a hybrid DMFC and Ni–Cd battery hybrid power source. When load shows a sharp rise, the fuel cell reduces output voltage and increases output current sharply. The battery also shows a voltage reduction and an increase of output current. Moreover, the fuel cell shows a stable transient characteristic for some seconds in the beginning of load growth. This means that a transient current protector is necessary because of instantaneous overload when the hybrid power system is used as a power supply for portable equipment or precision equipment, both of which are sensitive to the characteristics of input current. The Ni–Cd battery did not shows a transient characteristic, proving to be stable. In the hybrid DMFC and Ni–Cd battery power system, the fuel cell and the battery showed similar levels of load following, and the transient characteristic was stabilized within a few seconds of setting time.

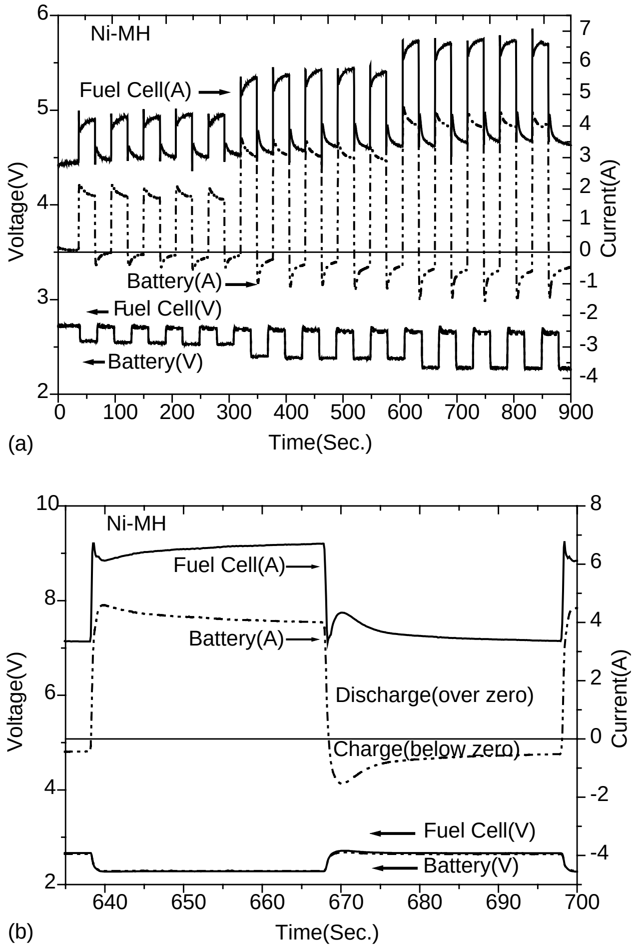

Fig. 8. (a) Constantly pulsed load characteristics of DMFC and Ni–MH battery hybrid power source. (b) Typical transient current response on the application of a voltage interrupt (Ni–MH 2.4 V, 2 Ah).

When the load shows a sharp decline, the fuel cell raises its output voltage sharply and reduces the output current fast. The battery also shows a voltage rise and a reduction of output current. In this case, also, the transient characteristic appears because a fuel cell drops its output current sharply. This transient characteristic of the output current of the fuel cell does not get stabilized soon, requiring a setting time of longer than 1 min. In other words, frequent and sharp changes in the load in the hybrid fuel cell system may damage the fuel cell. The figure shows that surplus power output is charged to the battery when fuel cell increases output. In other words, 'below zero' current of the battery means that the battery is in a charged state. Fig. 7b shows the typical transient current response on the application of a voltage interrupt.

Fig. 8a shows the constantly pulsed load characteristics of the DMFC and Ni–MH battery hybrid power source. This is same as in the case of the Ni–Cd. However, the Ni–MH battery shows that its current growth is lower than that of the fuel cell, as is shown in the experiment. This is presumably because the fuel cell performed better in response to a pulsed load due to the battery low energy density. Fig. 8b is the same as in the case of Fig. 7b, but he Ni–MH battery shows better charge and discharge characteristics compare with the Ni–Cd battery.

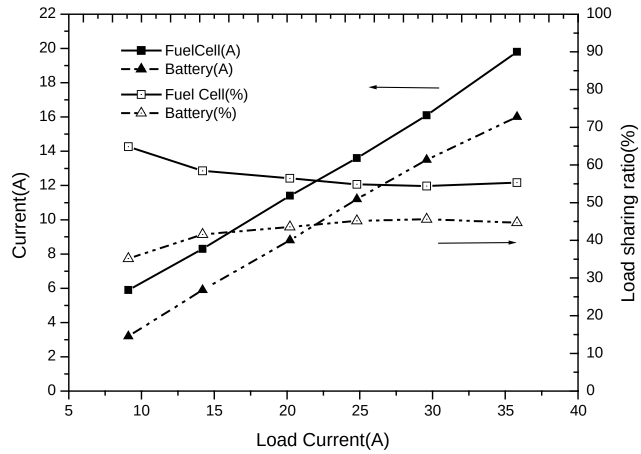

Fig. 9. Load sharing ratio of DMFC and Ni–Cd battery hybrid power source (Ni–Cd 2.4 V, 5 Ah).

Fig. 9 shows the load-sharing ratio of the DMFC with the Ni–Cd battery hybrid source. The load following ability of the Ni–Cd battery was similar to the DMFC in all power ranges. The load sharing ratio of the fuel cell is two times in contrast with the Ni–Cd when the load current is lower than 10 A, but the load sharing ratio of the fuel cell is 1.5 times comparing with the battery when the load current in higher than 20 A.

3. Conclusions

To develop a DMFC/battery hybrid power system, a connection apparatus with a DMFC and a battery was set up. The load share and the fuel cell/battery dynamic characteristic was measured and analyzed.

This experiment showed following results:

- If the load power increase constantly, the output ratio of the battery was higher than that of the fuel cell
- To use the battery for an auxilious power source, needs a booster of output voltage control
- The fuel cell and the battery showed similar follow-up characteristics of load
- The Ni–MH, Ni–Cd and Pb batteries showed good hybrid characteristics
- The transient characteristic of the output current of the fuel cell requires a setting time of longer than 1 min, and frequent and sharp changes in load may damage the fuel cell
- The load-sharing ratio of the fuel cell in the fuel cell/battery hybrid power system was 2 and 1.5 when the load current was lower than 10 A and higher than 20 A, respectively

Analysis of the load-sharing characteristic of the fuel cell and the battery hybrid power was undertaken. Since, however, the load change brought about a wide range of fluctuation in the voltage of the fuel cell, it was very difficult to experiment with the hybrid power system. A sharp change in the load of the fuel cell is may damage the fuel cell.

If we adopt a booster for controlling the output voltage of the fuel cell on the basis of the power system using the proposed hybrid fuel cell and battery power supply, it will be possible to commercialize a high-efficiency next-generation power supply without causing any pollution, to solve environmental problems and to contribute to energy saving, within a short time.

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