## B-14.3.2 Battery Management of Electric Vehicle for Commuters (Final Report)

**Contact Person** Ken-ichi Shimizu
Head, Energy Eco-Use System Div. Energy Dept.
Mechanical Engineering Lab. AIST. MITI..
Namiki 1-2, Tsukuba, Ibaraki, 305 Japan
Phone +81-298-58-7062 Fax. +81-298-58-7275
E-mail shimiken@mel.go.jp

**Total Budget for FY1994-FY1996** 19,867,000 Yen (FY1996; 6,792,000)

**Abstract** Wide spreading of electric vehicles (EVs) is anticipated to reduce the emission of carbon di-oxide in traffic use. In practical EVs operation, un-conditional battery management leads the battery pack to severe functional disease, and this reduces the EV efficiency and the life of battery system significantly.

In this study, the prototype battery management system, that can monitor the dynamic information of each battery cell under the operating condition, has been made to improve the efficiency and life of the battery system of EVs. Utilizing this system, causes and mechanisms of this functional disease were clarified. The result shows that one of the main causes is un-uniformity of cell condition, (but un-uniformity of module battery condition) and once the un-uniformity occurred particular cell capacity falls in a high rate due to its frequent over charge/discharge conditions. This result was confirmed by checking the un-uniformity in practical EVs battery pack used nearly two years.

This system was also applied to manage the charging/discharging operation in practical EV settled on chassis dynamometer to find the proper managing algorithm during simulated driving test. The result shows that it is essential to manage the cell voltage (but module voltage) to prevent un-uniformity of battery pack. The result also shows that the charging procedure for equalizing is another key technology to improve the efficiency and life of battery system.

**Key Words** Electric Vehicle, Battery Management, Range

### 1. Introduction

In spite of regulations on vehicle emission, air pollution caused by vehicle traffic has become a serious problem in many big cities because of the tremendous increase in vehicle numbers. From the consideration of global warming alone, it is important to reduce the volume of carbon dioxide generated in transportation use. It is also important to find an energy source alternative to limited fossil fuels.

These considerations have led to the development of the electric vehicle (EV) as a transportation possibility among next-generation transport candidates because of its potentiality low pollution, energy conservation and acceptability of different energy sources.

The performance of battery packs in the practical EV is, however, markedly lower than that of the nominal value promised by single module batteries. This poor performance is caused mainly by nonuniformity in battery performance. The best way to improve overall EV efficiency, thus seems to be to improve battery pack performance.

In this paper, we propose the individual management of battery cells, and discuss the results of trial runs using a microprocessor-based prototype system.

## 2. Actual Status of Non Uniformity in Practical EV Battery Packs

Used battery modules of the actual EV battery packs were tested to investigate the status of non uniformity in practical EV battery packs. Eight weaken modules were chosen in the two battery packs of 2 micro EV vans.

Pin holes were made in the case wall between each cell, and lead wires were inserted into this hole to contact connecting conductors between cells. Lead wires were used to detect cell voltages. Battery temperatures were measured by thermocouples installed in the cell.

Effective capacity of each cell is investigated through the charge/discharge test. Typical result in Fig. 2 shows that performance of a cell is significantly lowered and the other cells have still enough performances. Fig. 3 shows effective capacity of the 8 module batteries tested. The result shows that some module has weakened cells, and 4 modules of them has significantly lowered cells in fourth cell. This lowered cell reduces module performance, and this lowered performance of the module reduces the pack performance

If nonuniform battery capacity in a battery pack occurs, a battery with less capacity reaches a fully charged condition sooner than remaining batteries in the pack. Overcharging of this battery continues until the overall battery pack voltage reaches a certain voltage.

In a sealed (valve-regulated) battery, electrolyte is discharged through the valve, and the effective capacity of this battery decreases further. In discharging, a battery with less capacity reaches a fully discharged state earlier than the other batteries in the pack, and it is forced to discharge as long as the battery pack is discharging. Repetition of this positive feedback phenomenon forces a battery with less capacity to radically reduces its capacity. Accordingly, to prevent this phenomenon, it is necessary to control each battery (or cell) so that the voltage does not deviate from a certain range.

## 3. Technical Trends in Battery Management System

Battery management systems were designed to solve the problems discussed in the previous section. These management systems can be classified into two types. One is a terminal voltage battery monitoring system represented by the BADICHEQ system.[1] Each battery's voltage is measured sequentially by a scanning system. In discharging, terminal voltage below the minimum voltage is checked and the signal is fed to the vehicle controller to prevent severe discharge in certain batteries that have no capacity. In the charging, high terminal voltage exceeding the maximum voltage is monitored. If a battery exceeding this level is detected, charging for the battery pack is terminated and the insufficient capacity of each battery is charged individually through a monitoring circuit using a small charger. This system requires a number of harnesses for detecting the terminal voltage of each battery. It also requires countermeasure against short circuits on each detection line. The other type of battery management system is an individual charging system for each battery in the EV battery pack. This system has the disadvantage of high cost, although it secures optimal charging conditions for each battery.

The status of the charge must be known by a state of charge indicator (SOC indicator) to interpret the distance to be covered by the energy remaining in the battery pack. It is important for the practical SOC meter to convert its own scale to fit the deviation of battery characteristics such as battery lifetime and temperature. Although various SOC meters have been proposed, no practical meter has yet emerged.

## 4. Proposed Battery Management System

The previous section shows that a lack of uniform battery characteristics in an EV battery pack adversely affects battery pack performance. Actually, the actual cause for low battery efficiency may be lack of cell uniformity in the battery, so it is essential in monitoring the uniformity of an EV battery pack to monitor cell voltage directly. The management system described earlier that monitors terminal voltages of batteries sequentially by mechanical/electrical relays has the following drawbacks in monitoring cell voltage:

1) Due to the large number of cell voltages to be measured, it is difficult to measure all voltages simultaneously.
2) Since EV system voltage has a tendency to shift high, it is difficult to get sufficient resolution and sufficient insulation voltage.
3) Because of the tremendous number of harnesses for detecting cell voltages, there is a practical difficulty with this system. It also has huge problems in having to set safety devices on each detection line to protect against unexpected short circuits on the detection line.

In this paper, we propose a cell voltage monitoring system for an EV battery pack. This system can detect the cell voltage, module temperature, and current of the main circuits simultaneously. One aim of this system is to reduce the number of harnesses and to eliminate the problem of insulation and/or resolution of measurement.

The proposed management system is composed of a microprocessor-based manager and sensing units installed in batteries. Sensing units are connected to a manager with a serial communication line (Fig. 2).

Various types of communication line can be chosen in accordance with the vehicle situation, for example, twisted pair, optical fiber, radio or a modulated carrier on the main circuit. The manager has the following main functions:

1) Control of the measuring timing (normal/history mode)
2) Control of the sensing unit (simultaneous/sequential)
3) Estimation of individual cell charge status by the source voltage and internal resistance of each cell
4) Control signal for the motor controller/charger (threshold current to be limited on charge/discharge)
5) Battery maintenance information (history information on cell/module)

Figure 3 shows a block diagram of the sensing unit. The sensing unit is composed of sensors for sensing cell voltage, a thermosensor for measuring the typical temperature of the battery, a CPU with buffer, and a communication module.

The sensing unit is an intelligent instrument, and its power is fed by each battery. Responding to commands from the manager, a series of measurements is performed, and the resultant data is saved in a buffer. This data is transferred to the manager in response to a transfer command from the manager. Each sensing unit has its own address, and the manager can perform asynchronous communication with each unit sequentially. It is also possible to communicate within a certain groups in which a detailed check is required.

It is necessary, for the battery pack with high system voltages, to insulate each sensor.

For this requirement it is easy to insulate each sensor by communication line, insulation by optical coupler, for example.

This sensing unit should be composed using a specially designed module or chip, and it should be installed in each battery. In this paper, the sensing unit is composed of conventional circuits to check system characteristics.

5. Cell Monitoring Using Prototype System

The prototype system has been constructed of conventional board computers and PCs to confirm system adequacy. Charging/discharging tests were conducted using this system to clarify the effect of cell voltage monitoring.

Two test batteries (fluid battery for cycle service use, 12 V, 50 Ah) were installed in two water baths separately (Fig. 4). The temperature of each water bath were kept at 30 ℃ and 40 ℃, so that non uniformity in the batteries occurred easily.

Charging/discharging current was controlled by adjusting the output voltage of a four-quadrant power source so that output current is equal to the target value. Two module batteries were connected in series and the charging and discharging tests were conducted alternately. The batteries were charged by the same algorithm as that of the charger designed for these batteries (quasi constant voltage). The batteries were discharged at a constant current of 10 A (0.2 C) until the terminal voltage fell below 20.4 V ((1.7 V/cell)x12). This value is derived from the lowest voltage for 0.2 C discharge at 30 ℃. Charge/discharge was started after 30 minutes of rest after discharge/charge. Water for batteries was replenished every 5 or 6 cycles to suppress the effect of watering.

Performance of the battery kept at 40 ℃ reduces drastically after 285th cycle. The life of battery pack (285 cycles) is less than 60% of module life (500 cycles). Figure 6 shows variations of cell voltage in 291st cycle; (a) is result of the tested battery kept at 40 ℃, (b) is one at 30 ℃. The performance of the 4th cell at 40 ℃ falls drastically, and this cell can not be recharged yet. This phenomenon causes the shortening the life of the battery pack. Figure 7(a) and (b) show the cell temperature variation in the same period, respectively. It is interesting that each cell temperature varies irregularly in (a), hence it varies regularly in (b).

It is important for prevent overcharge/discharge to manage the battery system using a cell-based procedure.

6. Probability of State of Charge Estimation

The previous discussion was based on charging/discharging in a constant current. In this section, battery variations in the driving cycle test and the probability of the state of the charge indicator are discussed. Four-mode driving cycle tests of the micro-EV (Hijet EV) were conducted on an EV chassis dynamometer, using a driving robot. The acceleration period of the driving cycle is modified on a large scale to ensure a similar load condition for the tested vehicle as in traffic use.[2)]

Due to a lack in the number of board computers, module base measurement was performed instead of cell base measurement. Terminal voltage and battery current were measured every 2 seconds, and voltage-to-current curves of each module battery were displayed on screen in real time. Figure 8 shows the voltage current characteristics of each battery and the total battery system. Each line in the figure shows the V-I characteristics for one driving cycle. Interception of the Y axis shows the source voltage of the battery and the gradient shows the battery's internal resistance. For No.1 and No.8 battery, performance falls significantly in proportion to the driving cycle. For the total battery system, the drop in performance is not so severe. If a vehicle controller monitors only system voltage, it is difficult to detect the severe performance drop in No. 1 and 8. As mentioned previously, cell-based monitoring is required to prevent the reduction of battery performance.

Kitagawa developed an SOC meter based on an ampere-hour meter technique and internal resistance measurement of the battery pack. He improved SOC estimation accuracy by modifying the resultant estimation by the ampere-hour meter with battery resistance in the low SOC range.[3)]

Variations of battery source voltage and battery internal resistance derived from Fig. 8 are shown in Figs. 9 : sensitivity of internal resistance to the SOC is higher than that of source voltage. Since the battery pack performance is limited by the performance of the battery (or cell) whose performance in the pack is lowest, SOC should be estimated by the scale for the battery with lowest performance. In this system, higher accuracy and practicality can be expected in comparison with the conventional SOC meter, which estimates information for the battery pack.

7. Summary

A practical battery monitoring system that can check a number of cell voltages and other physical values simultaneously has been proposed and a prototype system has been developed using conventional components. By a trial run of this system in the charging/discharging test of a small-scale battery pack, we clarified that the system has good enough performance for preventing occurrence of nonuniformity in the battery pack.

Using monitoring data, the characteristics of each cell can be easily estimated in real time. This system was tested in driving cycle tests conducted on a chassis dynamometer, and the possibility of SOC estimation was checked. Results show that SOC estimation on the most damaged cell will lead to a practical scale.

The effects of battery temperature, battery life, and the applied pattern of the vehicle on SOC estimation is an important factor to be applied practically, and it will be an important subject for a future study to clarify this effect.

**References**

1)W. Retzlaff. "On Board Battery Diagnostic and Charge Equalizing System (BADICHQ)," Proc. of EVS-11, Florence (September 1992), [conference paper]

2)K. Shimizu, N. Shirai, and M. Nihei. "A Few Remarks on the Range Test of EVs- On the effect of Test Procedure In Acceleration/Deceleration," Proc. EVT'95, Paris (November 1995), [conference paper]

3)M. Kitagawa, H. Shibuya, and J. Takehara. "Development of Battery State of Charge Indicator for EV," Proc. EVS-13, Anaheim, CA (December 1994), [conference paper]

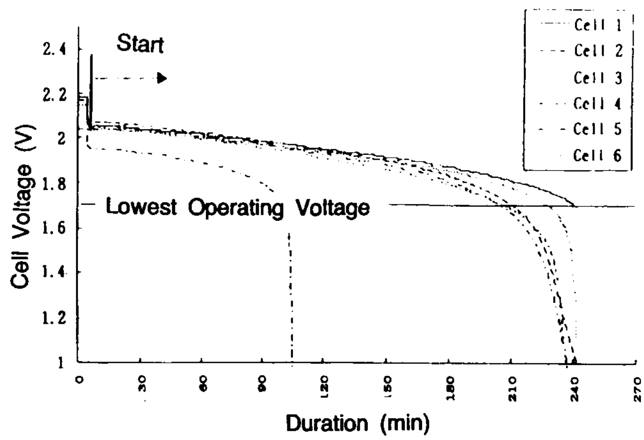

Fig. 1 Cell Characteristics in Discharging

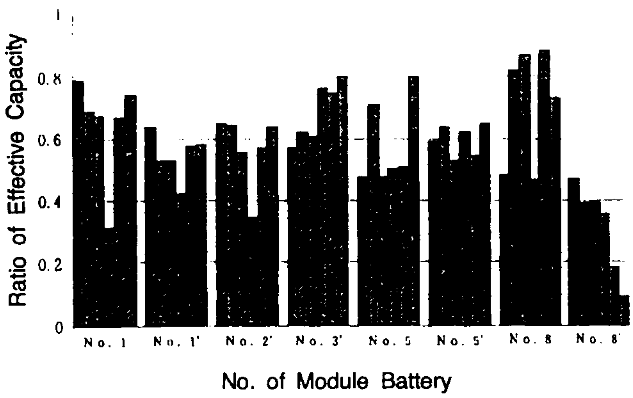

Fig. 2 Effective Capacity of Cell inUsed Module Battery

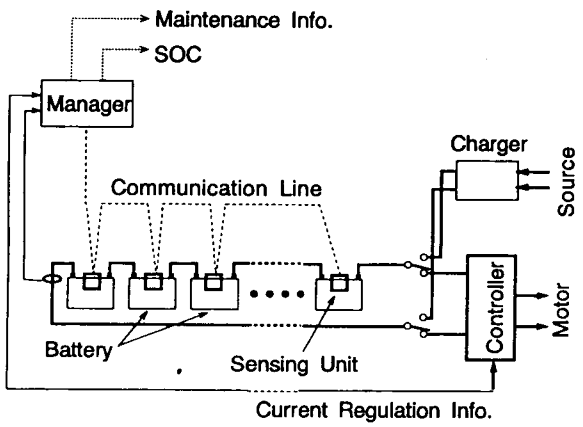

Fig. 3 System Block Diagram

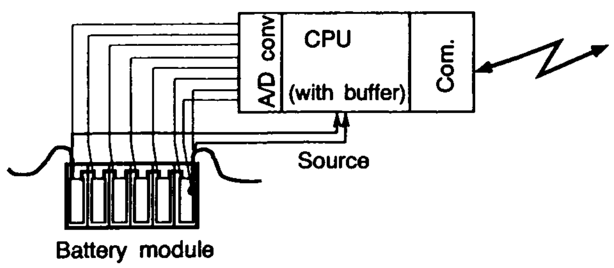

Fig. 4 Sensing Unit Block Diagram

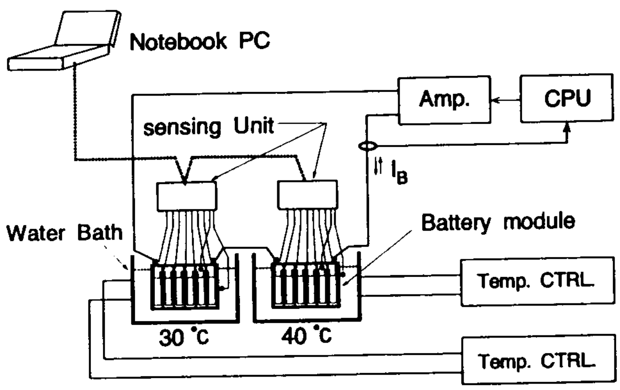

Fig. 5 Block Diagram of Test Bench

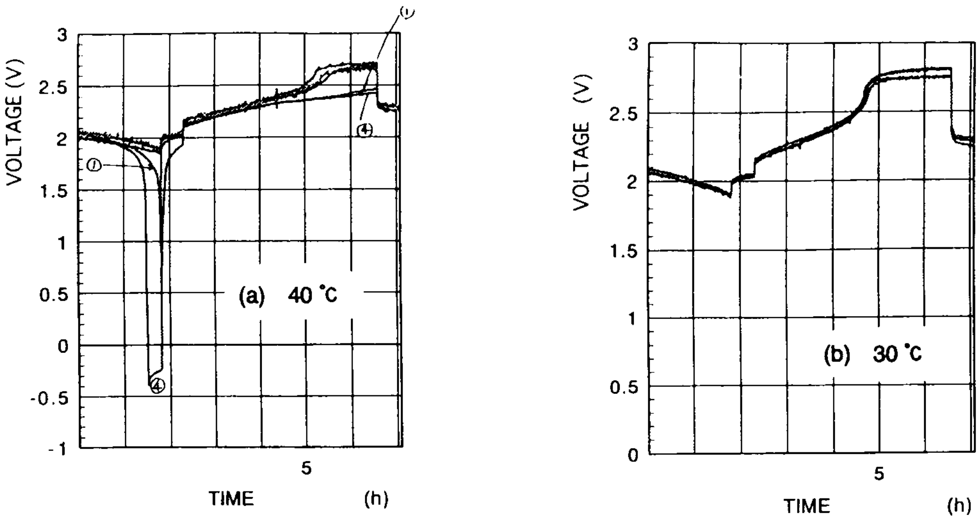


Fig. 6 Cell Voltage variation in the Charge/Discharge Test

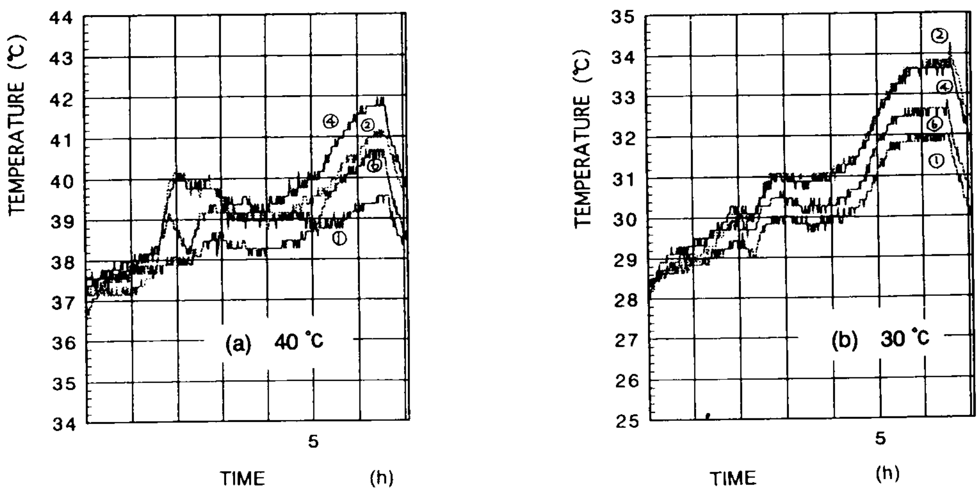


Fig. 7 Temprature Variation of Tested Batteries

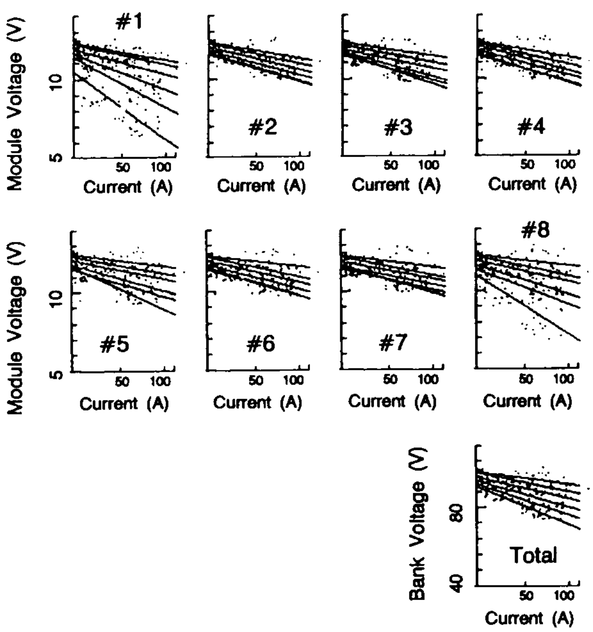


Fig. 8 V−I Characteristics
of Each Module and Battery Bank

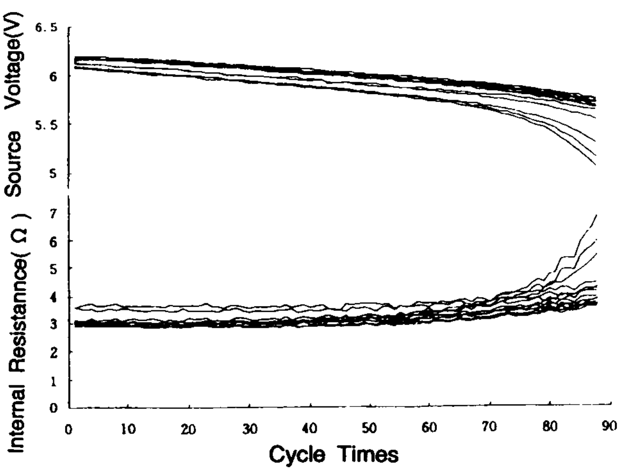


Fig. 9 Variation of the Battery Source Voltage/
Internal Resistannce