B-55.4 Improvement of life cycle cost of electric vehicles (Final Report)

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Charging/discharging efficiency (including charger efficiency) is the one of the key factors that determines total energy efficiency of EV systems. The lifetime of battery banks is also the key factor to determine the environmental impacts of EV system from the viewpoint of life cycle Assessment (LCA). To improve LCA of EV system we proposed simple battery management system, and have studied how to use the system.

Results of charging/discharging test with the proposed simple battery management system showed that charging/discharging watt-hour efficiency is improved up to 90%.

Another key function of the battery management system is to estimate the state of charge (SOC) level of the battery under the normal driving conditions or charging conditions. We confirm the system ability of estimating SOC of the each cell under the mentioned conditions, through the simulated driving test conducted on chassis dynamometer.

Key Words Electric Vehicle, EV, Battery Management, Energy Economy

1. Introduction

Energy efficiency of EV system is largely affected Charging/discharging efficiency (including charger efficiency) rather than efficiency of EV itself. The LCA of EV system is also affected by the life times of battery banks.

The lack of uniformity in battery characteristics in a battery pack limits the effective capacity of the pack and shortens the life of the pack. The conventional series charge and series discharge of a battery pack, which has certain non-uniformity in some cells, worsens the non-uniformity in the pack. Repetition of this phenomenon results in the battery pack becoming extremely non-uniform. For valve regulated lead-acid batteries, this phenomenon causes weakened cells to dry up. As it is fatal for a cell to overcharge and exceed the gassing voltage or over-discharge and exceed the permitted lowest voltage, it is imperative for the battery controller to prevent non-uniformity among cells in the battery.

To improve LCA of EV system we proposed simple battery management system, and have studied how to use the system.

Another key function of the battery management system is to estimate the state of charge level of the battery under the normal driving conditions or charging conditions. We confirm the system ability of estimating the each cell SOC under the mentioned conditions, through the simulated driving test conducted on chassis dynamometer.

2. Energy efficiency of conventional EVs in service

Energy efficiency of conventional EVs in actual use is investigated referring the report on EV fleet tests. Figure 1 shows relationship between energy consumption and the range before charging of conventional electric micro van, that has the largest market share in

Japan. Both figure a and b shows the result of same type EVs used in same office. Differences are operator of each EVs. Energy efficiency of each figure shows same tendency to increase if EVs are charged in short travel. This phenomenon is caused by an increase in ratio of energy spent for equalizing charge and lower efficiency of charger in charging end period. But each amount of energy consumption differs. The EV is designed to adjust charging time referring to travel distance after last charge, to prevent overcharge in a short travel. So the manual of this EV recommends operator to set the timer installed in charger referring the travel distance after last charge. The operator "a " follows the recommended procedure, but the operator "b" does not. This example shows unconditional charge makes huge decrease in energy efficiency.

Another data in another reports show similar tendency. These data show that actual energy efficiency of charging process (ratio of energy in battery out to energy from mains) vary widely (58% to 80%). This fact means management of charging /discharging process is important to improve energy efficiency of EV system.

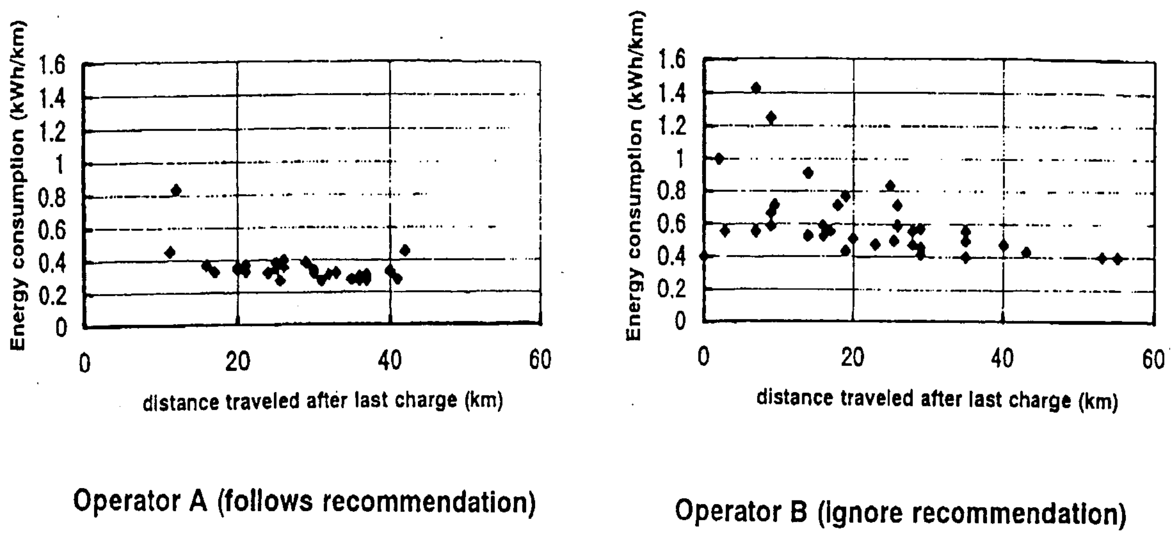

Fig. 1 Effect of the range between charging (an example of charging procedure effect)

3. Outline of the prototype system

Preceding study(1,2) clarifies that the non-uniformity of the cells in battery system causes more non-uniformity. This non-uniformity is one of the most serious subject to clear. To prevent non-uniformity of cells in battery system, a cell based battery management system is required.

To realize the practical cell based battery management system, we proposed a cell based monitoring system. A second prototype monitoring device for cell based management was developed for studying a practical control algorithm. A schematic diagram of the system is shown in Fig. 2. One monitoring device is attached to one individual battery module, and measures six cell voltages and two battery temperatures. The battery module to be monitored powers this device and devices are inter-connected with communication cables to each other. The communication line is isolated from each device, so each device is isolated from each other. This system has battery monitoring devices and one current monitoring device to get the current value and corresponding cell voltages as set data.

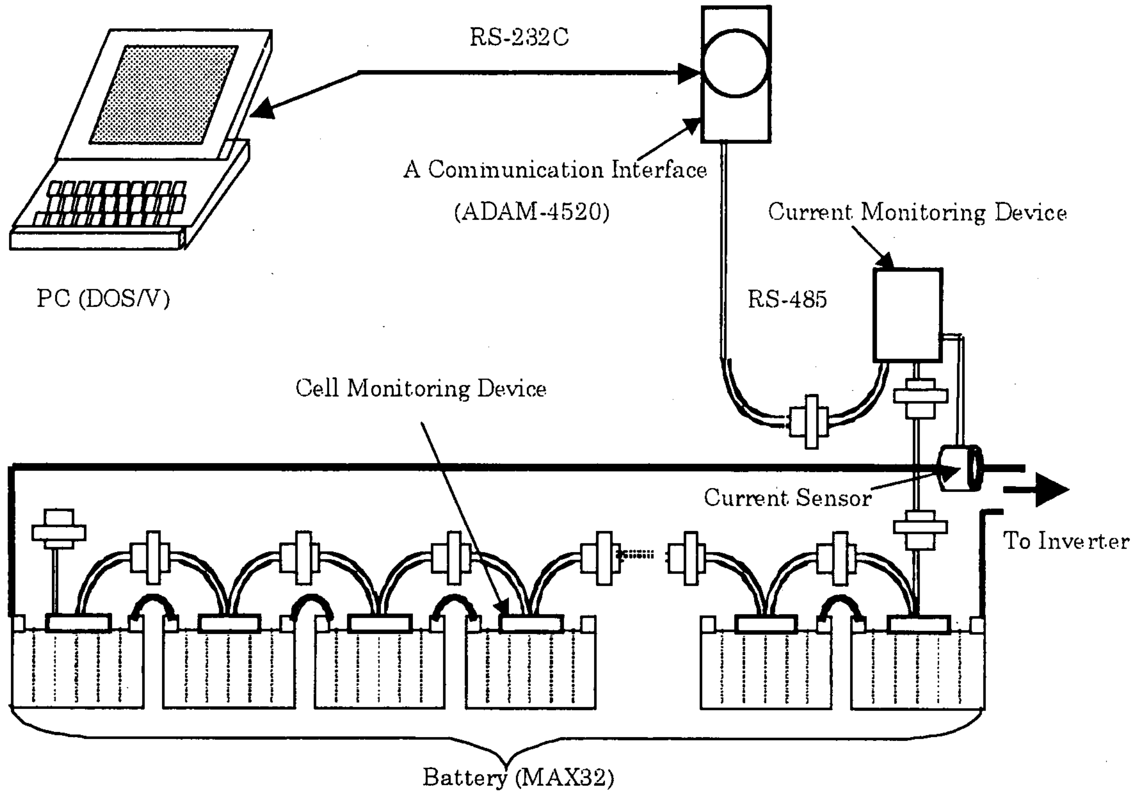

Fig.2: Schematic Diagram of Cell based Battery Monitoring System.

Table I Specifications of the cell monitoring device

Voltage input (6ch)	Range	: 0～18V
	Repeatability	: less than 1%
	Freq. char.	: DC～10 Hz
Temperature input (2ch)	Sensor	: T-type thermocouple
	Range	: -10～70℃
Communication I/F	Electrical char.	: RS-485
	Connecting type:	party line (multi drop)
	Speed	: 9600～19200 BPS
	Max. No. of devices:	32
Measuring mode	Single mode / burst mode	

The objective of this system is to enable the cell performance to be estimated under dynamic conditions such as practical driving conditions. This system has the advantage of high sensitivity in detecting low SOC level because of cell based measurement. So this system is practical enough, despite of poor sensor accuracy.

The main function of this device is to measure the cell voltages and temperatures when instructed by the controller, and to store the data in each device. An additional function is to send the data to the controller in response to a request from the controller. The specifications of this device are shown in Table I and typical commands for device operation are shown in Table II.

Table II Typical commands and their operation

*** Commands for data acquisition**	
Trigger (G)	Gives AD start signal to all devices
Set meas. mode (M)	Select measuring mode (single or burst mode)
Single mode	No parameter
Burst mode	Time interval: XX (in ms)
	Number of burst data : XXX
Request to transmit data (I)	Corresponding to specified address (XX)
*** Commands for system check**	
Transmit data to PC	(address data XX are required)
Check parameter stored (S)	Corresponding to specified address (XX)
Send parameter to PC	(address data XX are required)

Typical commands are issued in the following sequence:
1) Set measuring mode: All devices to be used should be set respectively.
2) Trigger: All devices start AD converter and store data in the devices respectively.
3) Request to transmit data: Collect the resultant data by sending a request command with the device address.
Steps 2) and 3) are repeated to collect new data.

Due to the huge number of cells in the EV system and limited communication speed, it is impossible to obtain all cell data. So, we collect the data on weaker modules in a short repetition cycle to acquire enough data to estimate the characteristics of the weakened modules in service. We collect the data on other modules with a relatively slow repetition cycle, for these data are necessary to check gradual deviation in the battery characteristics.

The value of battery current can be also obtained synchronously with battery voltage data, so internal resistance and electromotive force of the battery can be estimated from the relationship among these data. To collect these data effectively, voltage data corresponding to the various current values are acquired, so data are collected in the following manner during the driving period.

- Get the current data following the Trigger command to check the current value, and do not get new current data if current data does not vary enough.

This estimation was tried for a ten-mode driving cycle test performed on a chassis dynamometer. Figure 3 shows the result of this trial, and shows the variation of the internal resistance and the electromotive force of the battery. This figure indicates the possibility of estimating the SOC of the battery pack by using the weaker battery data as a scale for estimation.

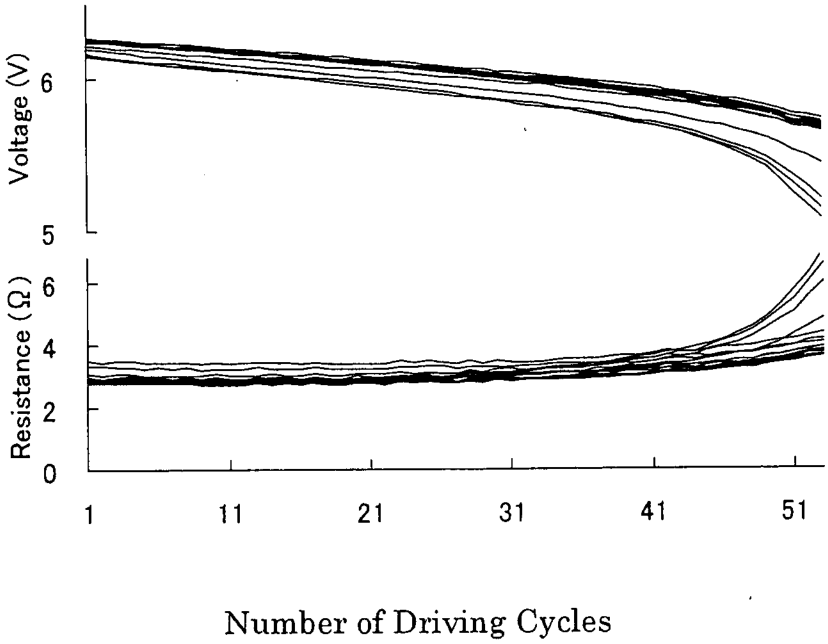

Fig.3: Variation of Battery Voltage and Resistance in Driving Cycle Test.

4. Efficiency of charging/discharging period

One of aim of the management system is to improve charging/discharging efficiency of the battery system. It is known that charging procedure is more affective to efficiency. Charging algorithm is studied to improve both efficiency and battery life. Figure 4 shows a result of charging / discharging test conducted under the control of battery management system. This figure shows variation of effective capacity and charging / discharging efficiency of the module battery. The efficiencies are measured both in Ah and Wh. The result shows this procedure can achieve 97% in Ah efficiency (efficiency of the conventional charging procedure is around 85%), and can achieve 90% in Wh efficiency.

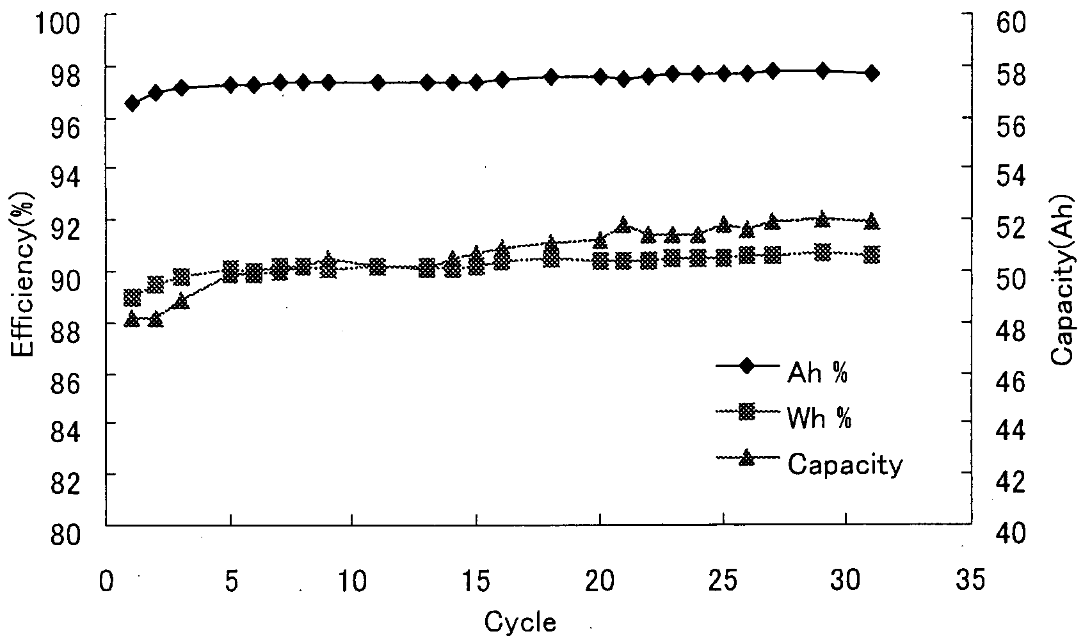

Fig. 4 Variation of the efficiency and effective capacity in charging/discharging period.

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