

Battery Control Technology of Li-ion Battery System for HEV

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ABSTRACT

The use of high-output lithium-ion batteries (LIB) is expected to enhance the vehicle performance of hybrid electric vehicles (HEV). However, LIBs are required to withstand long-term use when mounted in HEV.

This paper reports on a battery control system developed to help achieve LIB system durability. The use of an overcharge prevention system based on reliable voltage detection and a deterioration control system based on efficient charge state control enabled enhancement of durability while obtaining the maximum battery performance.

1. Introduction

Recently, various proposals have been made from a wide range of industrial sectors for the realization of a global low-carbon society. One such proposal is the further enhancement of hybrid electric vehicle (HEV) efficiency and popularization of HEV as a means of achieving higher automobile fuel efficiency. One device expected to help enhance HEV performance is the lithium-ion battery (LIB). The reason is that LIBs feature higher output and are lighter in weight compared to nickel metal hydride (Ni-MH) batteries.

Honda developed a LIB system for the 2011 model year CIVIC Hybrid. This system consists of 40 rectangular battery cells and is used for compact and lightweight parallel hybrid systems^{(1), (2)}. The motor is located between the engine and the continuously variable transmission (CVT), and assists running and performs regeneration when decelerating. Figure 1 shows the structure of the parallel hybrid system. The use of LIBs increased the assisting and regenerating outputs by 33% from the previous 15 kW to 20 kW, and further enhanced fuel efficiency. The battery box is 30% lighter and has 20% less volume than the previous model, and is contained in the Intelligent Power Unit (IPU). This IPU has approximately the same volume as the previous model but with higher system output. Figure 2 shows the structure and dimensions of the developed IPU.

In order to mount LIBs in vehicles, a system that can reliably prevent overcharging and deterioration control that extends battery life are needed to withstand long-term use. This paper reports on the system development.

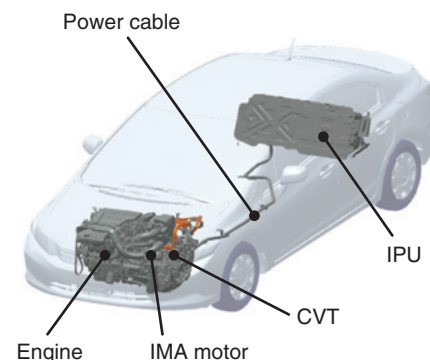


Fig. 1 Construction of Honda hybrid system

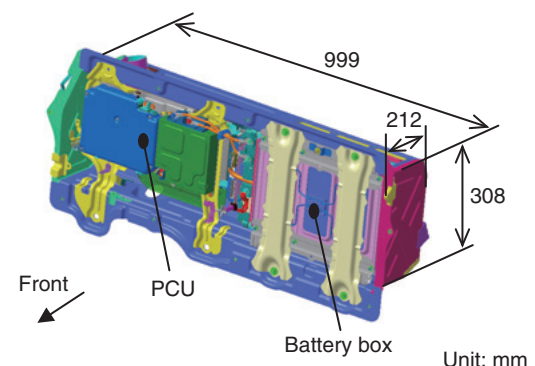


Fig. 2 Construction of IPU

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Table 1 Comparison of battery box specifications

	Developed	Previous
Voltage/Number of cells	144 (V)/40	158 (V)/132
Weight	21.7 (kg)	31.3 (kg)
Volume (Battery module)	14.4 (L)	15.4 (L)
Maximum output	20 (kW)	15 (kW)

2. System Configuration

2.1. Battery Box Specifications

Table 1 lists the specifications of the developed battery box. The use of LIBs enabled a 33% increase in output with weight reduction of approximately 10 kg. The battery box consists of four modules, each of which contains ten cells.

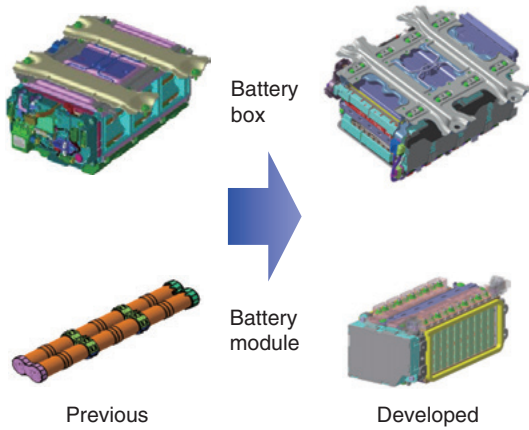


Fig. 3 Comparison of battery box and module construction

Figure 3 shows the battery box and module structures, and Fig. 4 shows the battery system diagram. The voltages of all cells are constantly monitored by voltage sensors and controlled by a battery ECU. In addition, the box has a mechanical switch and fuse at the electrically neutral point, and a contactor in the high-voltage output block. When the battery ECU detects a battery error, it operates the contactor to cut off the high voltage.

2.2. Battery Cell Specifications

Figure 5 shows the cell structure, and Table 2 lists the cell specifications. The criteria for selecting the battery materials were high thermal stability and high durability.

Figure 6 shows verification results obtained from the DSC (differential scanning calorimetry)⁽⁴⁾ tests for the thermal stability of different positive electrode materials. The developed battery uses ternary materials for the positive electrode, which gives it high thermal stability specifications.

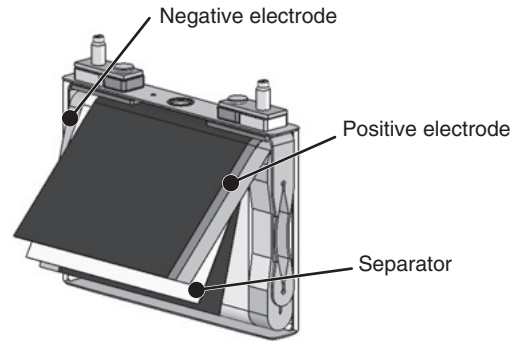


Fig. 5 Construction of battery cell

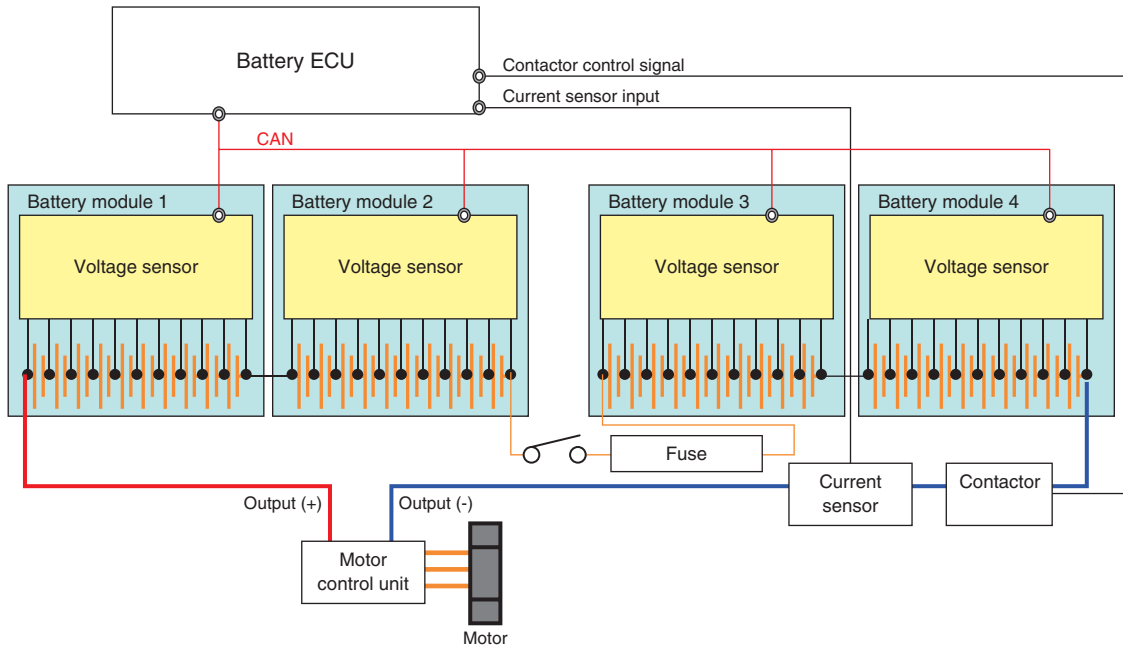


Fig. 4 System diagram of developed battery

Table 2 Battery cell specifications

Item	Description
Voltage	3.6 (V)
Volume	0.136 (L)
Weight	279 (g)
Positive electrode	LiNiCoMnO ₂
Negative electrode	Hard carbon
Case material	A3003 ⁽³⁾

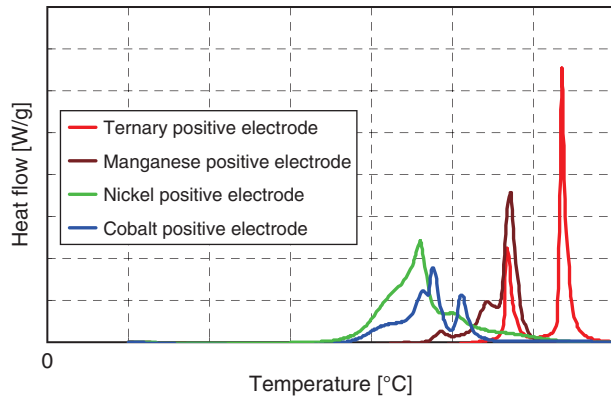


Fig. 6 Comparison of thermal stability among different positive electrode materials

3. Technology to Provide Durability

3.1. Overcharge Prevention System

Figure 7 shows the battery voltage behavior for differing states of charge (SOC). The Ni-MH battery voltage characteristics are shown on the left side, and the LIB voltage characteristics are shown on the right side. The Ni-MH battery charging efficiency drops in the high SOC range, and there is an SOC range in which the voltage does not rise even when charging is performed. On the other hand, LIBs have characteristics such that the voltage rises linearly with charging time even at high SOC. In addition, the cell voltage changes proportionately to the input charging current value, so SOC can be detected based on the cell voltage and current values. In order to reliably detect overcharging, the developed system detects the overcharge state using only the voltage value of the open circuit voltage (OCV) when SOC reaches its critical value.

To increase the voltage value detection accuracy, the Ni-MH battery performs voltage detection in 12-cell units as shown in Fig. 7. However, the LIB system has a cell voltage sensor for each cell to monitor each cell voltage value. The system also connects two voltage detection circuits with identical performance in parallel for each single cell as shown in Fig. 8, and constantly monitors and compares the values from these circuits to detect voltage detection circuit failures based on the voltage difference between the two circuits as shown in Fig. 9. In addition,

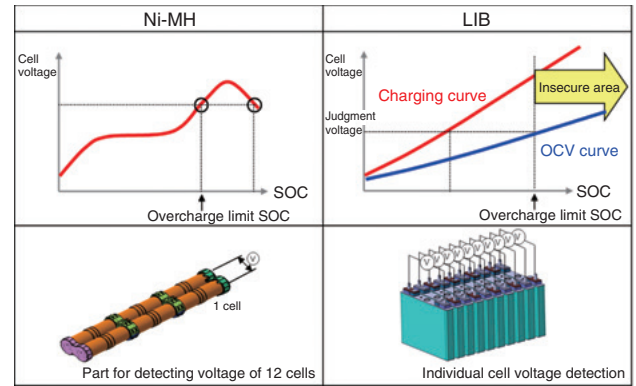


Fig. 7 SOC characteristics and voltage monitoring unit

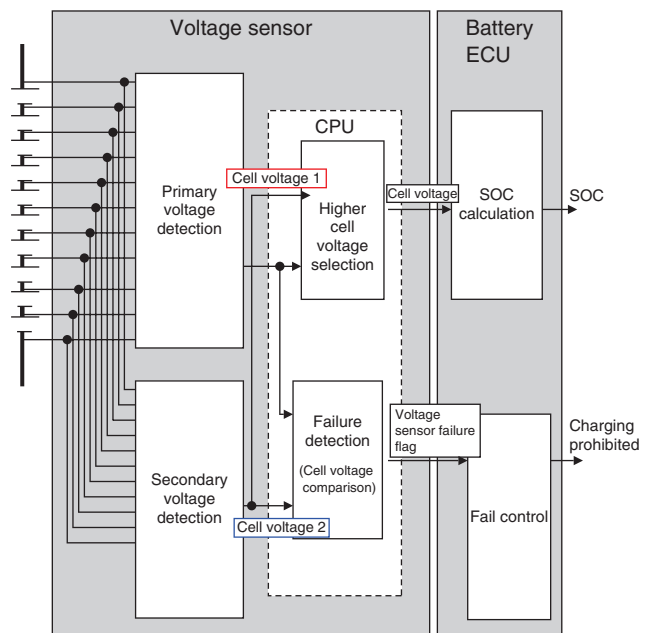


Fig. 8 Diagram of cell voltage sensor system

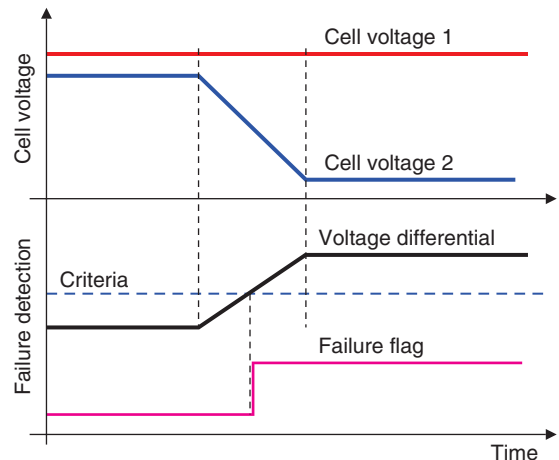


Fig. 9 Detection of cell voltage sensor failure

overcharge prevention reliability is further increased by comparing the voltage values measured by the two voltage detection circuits and selecting the higher value of the voltages.

3.2. Battery State Estimation and Deterioration Control

As batteries deteriorate, the usable capacity and output drop, so to provide the battery performance required by vehicles, it is necessary to accurately understand the SOC and cell capacity relative to battery deterioration. An adaptive battery state estimation system was constructed as a calculation method for this purpose. This system continuously estimates the battery internal resistance based on the voltage sensor, current sensor and temperature sensor information input to the battery ECU, and calculates the battery SOC and cell capacity.

The battery state estimation system consists of a real-time internal resistance estimator, an OCV observer, an SOC calculation block, and a battery capacity estimator (Fig. 10). The OCV observer continuously estimates the OCV based on the battery internal resistance value estimated by the internal resistance estimator. The SOC calculation block calculates the SOC from the estimated OCV. The battery capacity estimator continuously processes the change in the OCV and the change in the electric charge calculated from the current sensor information, estimates the battery capacity, and monitors the deterioration state (Fig. 11).

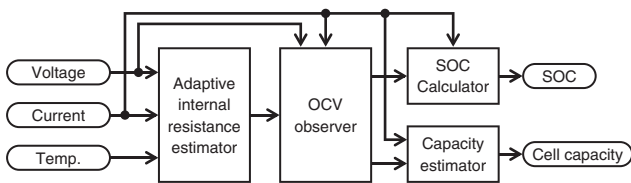


Fig. 10 Composition of adaptive battery-state estimation and control system

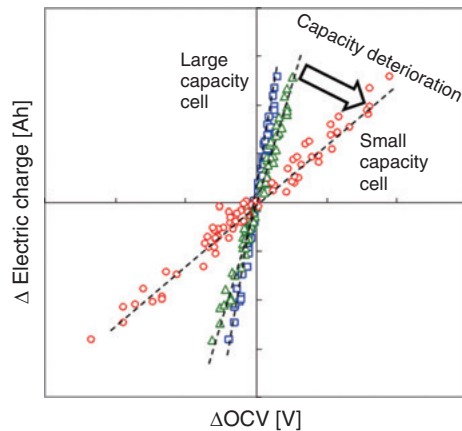


Fig. 11 XY plots showing characteristic change by battery capacity deterioration

Figure 12 shows comparative verification results between estimation results for SOC and battery capacity using the developed system and measurement results. This system enabled accurate estimation of the SOC and accurate calculation of cell capacity at the initial state as well as after battery deterioration.

Figure 13 shows the relationship between the battery SOC and durability. As shown in Fig. 13, battery deterioration progresses as the operating SOC increases. Based on this characteristic, it can be expected that battery life can be increased by performing control to achieve a lower SOC. However, there is the issue that, depending on the battery deterioration state, the energy and driving force required by vehicles cannot be secured at a low

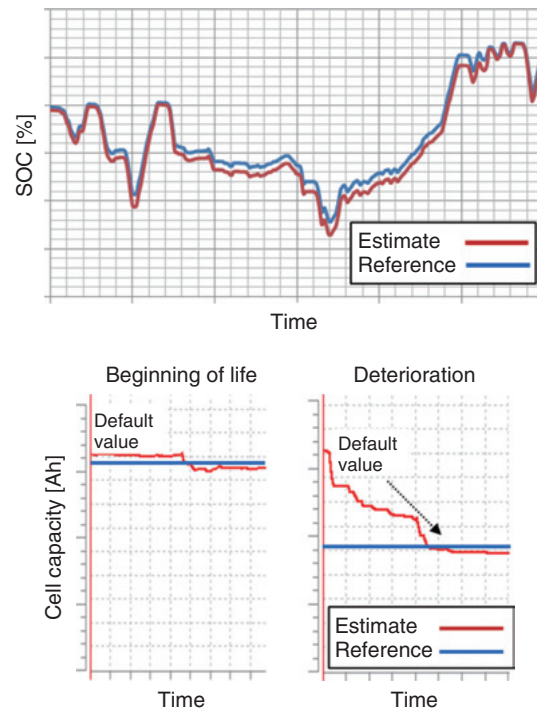


Fig. 12 Time charts of SOC calculation (upper) and battery capacity estimation (lower)

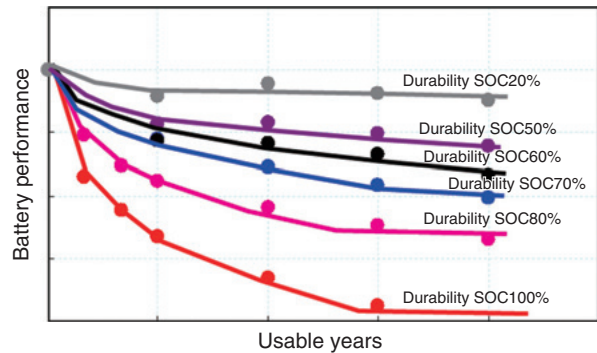


Fig. 13 Cell deterioration characteristics at different SOC

SOC. Therefore, the developed battery state estimation technology was used to construct the ideal battery control system.

In the initial state, when the battery capacity and output are sufficient, the SOC required for operation can be obtained without performing control to boost the SOC. When the battery has deteriorated after long-term use and a drop in the battery energy is detected, the battery performance required by vehicles is provided by shifting the SOC to the high SOC side as necessary. This method achieves the battery performance and battery durability required by vehicles (Fig. 14). This SOC control system suppressed the drop in performance as shown in Fig. 15, and extended the service life of the battery.

3.3. SOC Control between Cells

The developed SOC control system calculates the SOC separately for each cell. To provide durability, control must be performed so that the maximum SOC of each cell does not exceed the control SOC upper limit, and the minimum SOC does not fall below the control SOC lower limit.

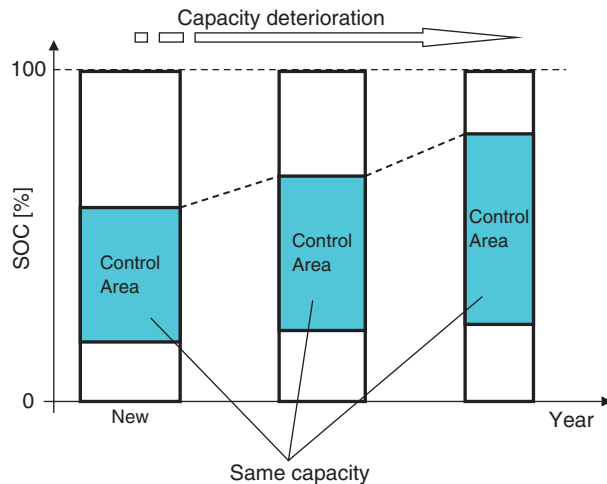


Fig. 14 Battery capacity deterioration

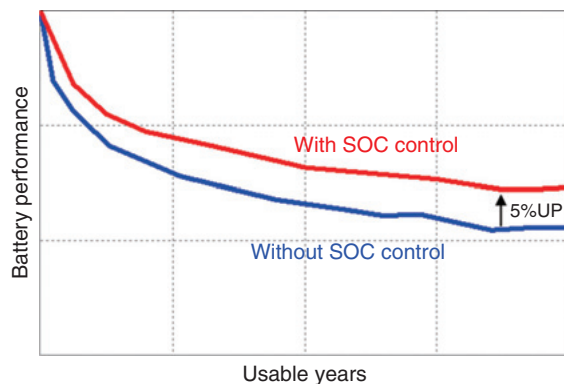


Fig. 15 Effect of deterioration control

When the SOC differs between cells due to the service conditions, as shown in the top part of Fig. 16, the upper and lower SOC limits of different cells restrict the available capacity width, even though the capacity of each cell has not dropped. This results in a deteriorated state with reduced effective charging capacity for a battery pack. To suppress this, the individual discharge circuits provided for each cell are operated to discharge cells with a high SOC in order to level the SOC and restore the chargeable capacity width for a battery pack (Fig. 16 bottom). This technology enables effective use of the battery pack performance.

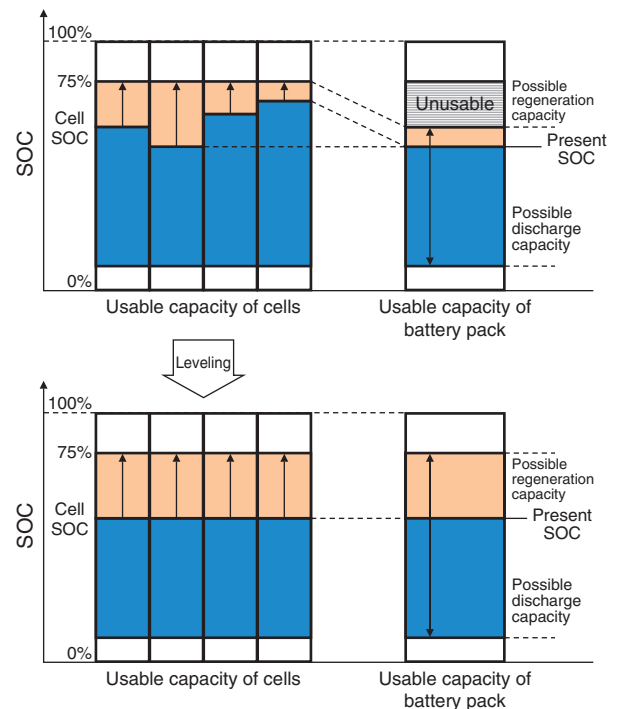


Fig. 16 Cell capacity leveling system

4. Conclusion

The following battery control technology was developed for LIB systems mounted in HEV.

- (1) To prevent overcharging, a system was constructed that can reliably detect overcharging. This system has a cell voltage sensor in each cell and also detects voltage sensor failure.
- (2) Technology was established that can simultaneously achieve the energy and driving force required by vehicles and durability. This technology constantly calculates the battery state (SOC and capacity of each cell) and performs control to maintain the ideal SOC.
- (3) A discharge circuit is provided for each cell, and when the SOC differs between cells, discharge circuits are operated to suppress this difference in SOC to enable effective use of the battery performance.

References

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