Intelligent Charge and Discharge Control for Secondary Battery Cells

Bu-Il Jeon, Geun-Wook Lim, Hyun-Chan Cho, Igor Gaponov, Sang-Gil Yoo, Kyeong-Duck Choi

***Abstract*—This paper suggests an Intelligent Control Algorithm for optimizing the charge and discharge of Secondary battery. With precision control of voltage and current levels in secondary batteries, high performance in battery life can be achieved and the problems of overcharging and over discharging in batteries can be avoided. By regulating the charge and discharge currents in a battery, voltage can be balanced. As the behavior of temperature and impedance of a battery is highly non-linear in nature, balancing current and voltage is very difficult. This paper proposes an Optimizing Intelligent Algorithm which can efficiently control the voltage and current levels by overcoming the problem of non-linear behavior of impedance in batteries. Results of the proposed algorithm from control circuit in an experiment are shown to provide efficient control of voltage and current levels in a battery increasing the battery life.**

***Index Terms*—— battery balance, impedance of battery, intelligent algorithm, secondary battery cell.**

I. Introduction

Nowadays, for increased demand and lack of supply, the price of oil is rising in the world. It is easily predicted that this trend will maintain in the future. Furthermore, worries about the environmental problems such as global warming cause the toughening of the regulation regarding the outlet of wasted gas. In order to deal with situation of increasing oil prices and the outlet of exhausted gas, the substitution for oil is an urgent need. Therefore, the solution of using a majority of battery cells connected in series (secondary battery pack) having higher power and greater capacity have been proposed. [1].

Secondary battery packs are used in HEVs (Hybrid Electrical Vehicle), electric automobiles, electric bicycles. With precision control of voltage and current levels in secondary batteries, high performance and long battery life can be achieved and the problems of overcharging and overdischarging in batteries can be avoided. Most of existing charging and discharging systems cannot perform balancing in real-time, they just measure the voltage of battery cells and balance all of them using average voltage of the cells.

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Bu-Il Jeon, Geun-Wook Lim, and Hyun-Chan Cho are with the Department of Electronics engineering, Korea University of Technology and Education, Cheonan City, Chung-nam Province 330-708 Republic of Korea (corresponding e-mails: {jqndlf, geunwook, cholab}@kut.ac.kr).

Igor Gaponov is with the Department of mechanical engineering, Korea University of Technology and Education, Cheonan City, Chung-nam Province 330-708 Republic of Korea (e-mails: igor@kut.ac.kr).

Sang-Gil Yoo and Kyeong-Duck Choi are with Nexcon Technology Co., Ltd., Yobang-Ri 303-1, Sunggeo-Eup, Cheonan City, Chung-Nam Province 330-834 Republic of Korea (corresponding e-mails: {topysg, ckd}nexcontech.com).

This method is stable but has low performance because battery cells discharge until their voltages reach the average value which does not allow us to use the full power of battery.

In this paper, we propose intelligent charge and discharge system which is stable, efficiently uses the power of battery and can perform real-time control of the charging process. Intelligent charge and discharge control system is divided into sensing and controlling parts. Sensing part measures temperature, voltage and inflow current of battery cells. Controlling part acquires measured data and impedance of cells and controls state of charge and discharge using intelligent algorithm. Proposed intelligent system controls charge and discharge speed of each battery cell by controlling charging and discharging current flowing to cells from several transistors, which can also remove the hazard caused by batteries and make them work with high performance. The effectiveness of proposed algorithm and control circuit is proven through real experiment.

II. Concept of Secondary battery cell balance

In every system that uses the series of secondary batteries unbalancing is caused by characteristic differences in battery cells. If all battery cells' condition is same, we can calculate quantity of electricity Q_{celln} (Ah) by multiplying capacity C_{celln}(F) (the rated capacity of each cell) and V_{celln}(V)(voltage of each cell), as shown in (1):

$$\begin{aligned} &Q_{cell\ 1} = Q_{cell\ 2} = Q_{cell\ 3} = \dots = Q_{celli} \\ &Q_i = C_{celli} V_{celli} \ , i = 1,2,3,\dots, n \end{aligned} \tag{1}$$

When battery cells are unbalanced during charging process, as we can see on Fig. 1, battery control system will switch off the charging current if one cell has reached full charge for stabilization; this happens due to serial connection of battery cells. Therefore, the rest of the cells will not have high enough capacity because of one fully-charged cell. Moreover, during discharging process, fully-charged cell cannot be fully discharged because there are no other fully-charged cells and battery management system switches off the discharging current for battery pack stabilization. In this case, battery pack does not have best performance due to existence of non-fully discharged cells. Therefore, the cells must be balanced in order to use energy efficiently [2], [3].

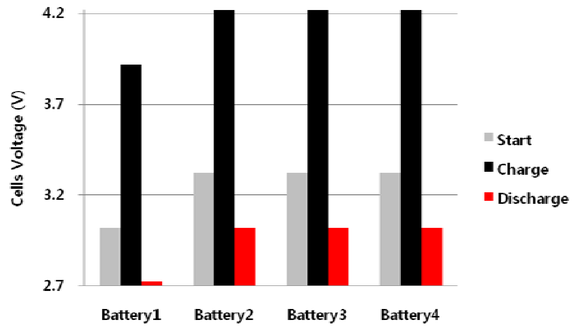


Fig. 1 Secondary battery unbalanced cells voltage

III. INTELLIGENT CHARGE AND DISCHARGE CONTROL

A. Current Control for Cell Balance

In real system, the charging current is controlled by difference in drain currents of charging transistors (TR) which are connected in parallel to battery and balance all cells at the same time. Transistor controls charging speed by controlling each cell's charging current. On Fig. 2, fundamental concept of a balancing system using a large number of transistors is shown.

When capacity of Cell1 becomes large comparing to others three cells, charging speed of Cell1 should become slower than in other cells. Control system reduces charge speed by decreasing charging current flowing to Cell1, which can be performed by choosing suitable TR1. During charging process, Charger feeds I charge to battery and current flowing to cell1 (I1) equals

$$I1 = I^{'}charge - I2 \qquad (2)$$

On Fig. 3, an intelligent cell balance system circuit which has been used in computer simulation is presented.

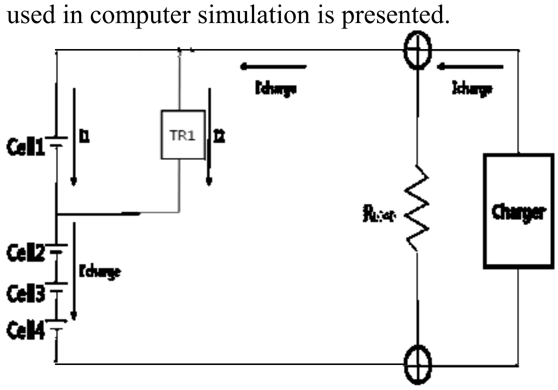


Fig. 2 Battery cell balance method

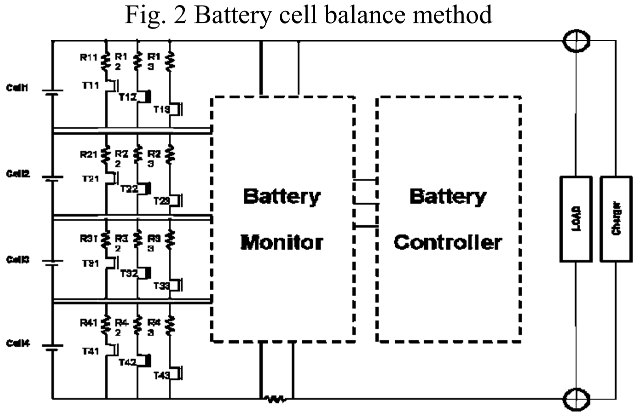


Fig. 3 Intelligent cell balance Circuit

Three TRs are linked in parallel with each cell in order to balance all four cells. Intelligent algorithm is loaded in Battery Controller and chooses signal for TRs.

Because parallel linkage of three TRs can give us eight possible control signals, we present them more detailed in Table I.

B. Intelligent Cell Balance

Table II shows change of impedance subject to lifecycle, value of impedance increases as lifecycle grows [4], [5]. If impedance is increasing, the charge speeds increasing quickly because capacity of cells is decreasing.

Initial characteristic of batteries are given in Table III and parallel linked TR1 selected on initial value of cells ("Cycle" denotes lifecycle of battery; "Ve" is for difference between each cell's received voltage and the minimum voltage of the cell.

After lifecycles passes, impedance (Z) of battery cells is changing as shown in Table IV, but all conditions except impedance remain same with initial conditions. If cell2 choose TR1, cells are unbalanced because charging speed of battery decrease due to battery capacity is small by impedance for battery increase.

Table I. Current control methods

Control1	All transistor(TR) OFF
Control2	TR1 is turned on
Control3	TR2 is turned on
Control4	TR3 is turned on
Control5	TR1 and TR2 are turned on
Control6	TR1 and TR3 are turned on
Control7	TR2 and TR3 are turned on
Control8	TR1, TR2, TR3 are turned on

Table II. Current control method

Lifecycle	Impedance changes [mΩ]
0	0 ~ 3.5
25	0 ~ 3.7
50	0 ~ 3.9
100	0 ~ 5.0
150	0 ~ 6.8

Table III. Initial characteristic of battery

	Cycle	Z [mΩ]	Ve [V]	TR
Cell1	0	7.0	0.5	TR1
Cell2	0	7.0	0.5	TR1
Cell3	0	7.0	0.5	TR1
Cell4	0	7.0	0.5	TR1

Table IV. Impedance of battery changes for life cycle

	Cycle	Z [mΩ]	Ve [V]	TR
Cell1	50	8.0	0.5	TR1
Cell2	50	9.0	0.5	TR2
Cell3	50	8.0	0.5	TR1
Cell4	50	8.0	0.5	TR1

This means that we need to change TR which was set earlier for battery balance depending on battery's impedance. Therefore, we propose intelligent control algorithm to change operating TRs properly.

Fuzzy algorithm controls TR charging current of cell using impedance of each cell and voltage of each difference between minimum cells' voltage (Ve) by input by output value.

Fuzzy algorithm consists of 3 consecutive steps [6], [7].

Step 1. Fuzzifier.

Table V shows the definition of linguistic variables used by Fuzzy algorithm. Two membership functions are shown on Fig. 4 and Fig. 5.

Fuzzy input and output variables used in fuzzy system are given by an isosceles triangles method which is widely used in existing control systems.

Fig. 4 shows input variable membership function of Ve that means difference voltage between all cells' voltages and minimum cell's voltage. Charging and discharging range of battery cells is from 2.7 V to 4.2 V, a variation of voltage is below 100 mV, therefore, so Ve varies 0 V to 1.3 V.

Fig. 5 presents the input variable membership function of Z (internal impedance change) calculated using thermal modeling of battery. Impedance changes from 0 mΩ to 6.8 mΩ during 150 cycles.

Fig. 6 represents output variable membership function of T about TR's selection for cell balancing.

Table V. Definition of Linguistic Value

VS	S	M	L	VL
Very Small	Small	Middle	Large	Very Large

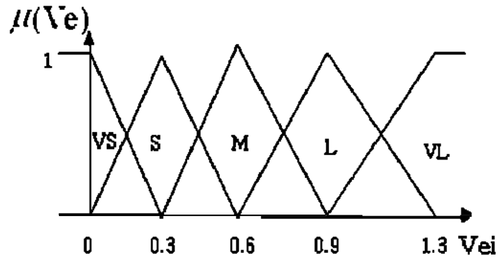


Fig. 4 Membership function of Ve

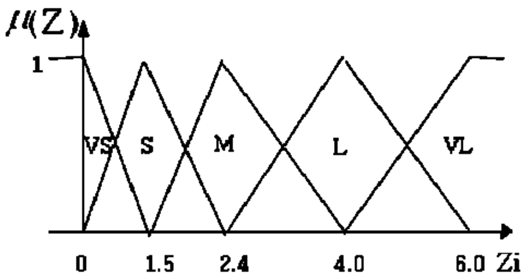


Fig. 5 Membership function of Z

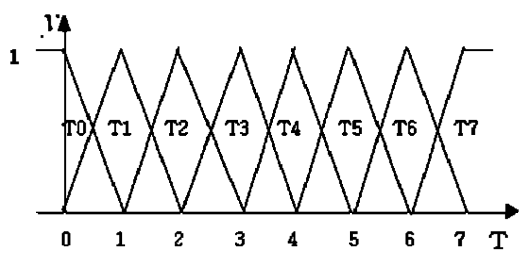


Fig. 6 Membership function of T

Step 2. Fuzzy rules and fuzzy inference

Table VI displays fuzzy rule for output T.

Table VI. Rule base

Transistor (T)		V				
		VS	S	M	L	VL
Z	VS	T0	T0	T4	T6	T6
	S	T0	T1	T3	T5	T6
	M	T1	T3	T4	T6	T7
	L	T2	T4	T5	T6	T7
	VL	T3	T5	T5	T7	T7

The reason why we apply fuzzy logic algorithm is that fuzzy approximation is used widely and implements simple control by using Mamdani's max-min compositional rule [6, 7]. According to the given rule, T0 does not select all transistors, T1 is TR1, T2 is TR2, T3 is TR3, T4 is TR1+TR2, T5 is TR1+TR3, T6 is TR2+TR3, and T7 selects TR1 + TR2 + TR3.

Step 3. Fuzzy rule and fuzzy inference

Defuzzifier uses simplified center of gravity method.

IV. EXPERIMENTAL RESULTS

A. *System Structure*

Experimental system for battery cell balancing measurement is presented on Fig. 7. It consists following blocks:

· Charger / Discharger (Constant 5A)
· System Power Unit
· Cell1, Cell2, Cell3, Cell4
· Cell Control Unit
· Intelligent Controller

Fig. 8 represents control flowchart for battery cells balance. At first, we check battery pack and, in case of overcharge, stop charging. After we have checked state of electric cell pack, we set charging current/voltage and sensing part sends voltage, current, and temperature to controlling part. Controlling part selects suitable TR and launches fuzzy algorithm to calculate Ve and Z. If cells balance is completed, we stop the process; otherwise, we perform battery pack check again and repeat balancing until all cells are balanced.

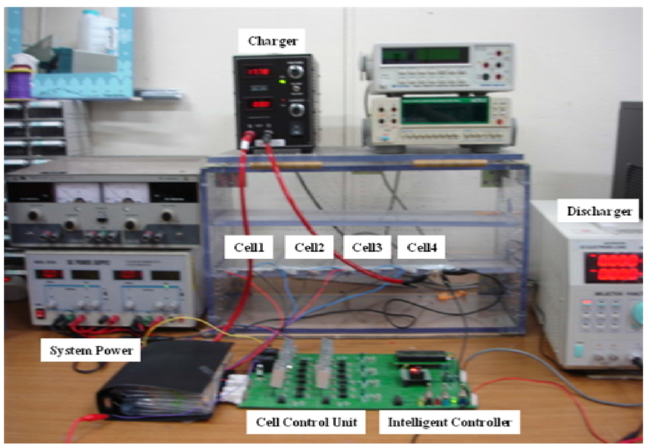


Fig. 7 Experimental system

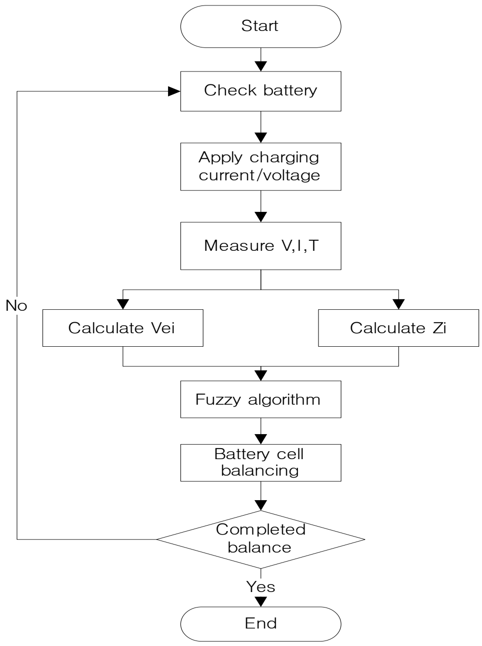
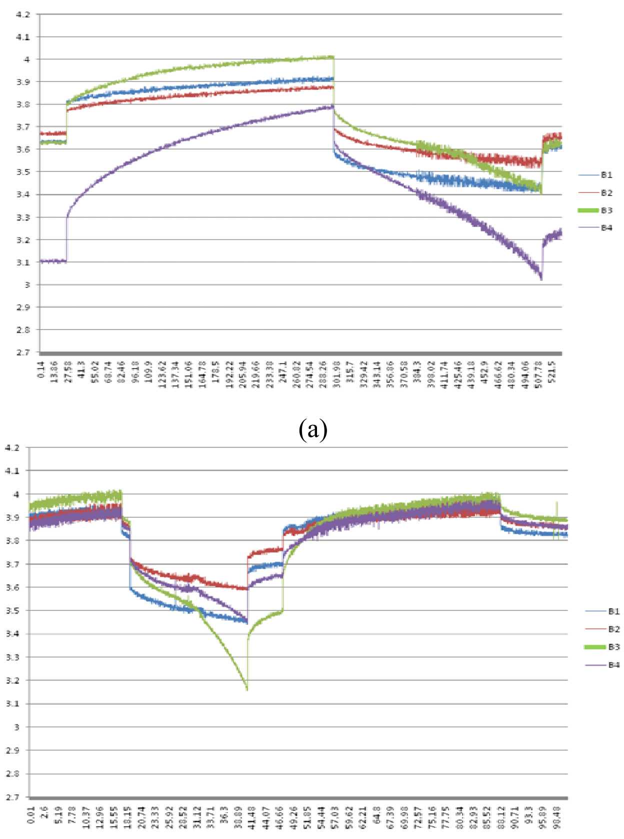


Fig. 8 Control process flowchart

B. *Experiment data comparison*

When cells are unbalanced, we measure internal impedance and implement intelligent algorithm.

Fig. 9 shows two charts representing no balance case (a) and intelligent balancing control case (b). A horizontal line shows time and a vertical line shows state of charging voltage of cells. We consider over-charging if voltage is greater than 4.0 V and over-discharging when voltage drops lower than 3.0 V; sampling time equals 100 ms. B1, B2, B3, B4 are battery cells.



(a)

(b)

Fig. 9 Cell voltage as a function of time

A comparison of unbalanced case (a) and intelligent algorithm case (b) can be made based on data from Table VII.

Table VII. Balance comparative analysis about each case

Analysis	cell1 (V)	cell2 (V)	cell3 (V)	cell4 (V)	V_{sum} (V)	V_{aver} (V)	V_{diff} (V)	V_d (V)
Before Balancing	3.918	3.874	4.018	3.779	15.589	0.095	0.411	0.239
After Balancing	3.962	3.923	4.011	3.967	15.863	0.031	0.137	0.088

V_{sum} is sum of cells' voltages, V_{aver} is average declination of cells' voltages, V_{diff} is total voltage difference between maximum voltage (16 V) and V_{sum}, V_d is voltage difference between maximum and minimum cells' voltages.

In no balance case, battery management system will switch off the charging current for stabilization due to serial connection of battery cells because cell3 is fully charged. Therefore, the rest of the cells will not have high capacity because of the fully-charged cell. V_{sum} is 15.589 (V), V_{diff} is 0.411 (V) and V_d is 0.239 (V).

When we balance cells using internal impedances and implementing intelligent algorithm, V_{sum} is 15.863 (V), V_{diff} is 0.137 (V) and V_d is 0.088 (V).

V. Conclusion

This paper describes intelligent charge and discharge control system for secondary battery cells that considers impedance of cells which changes non-linearly according to charge and discharge cycle of secondary cells.

For real time cell balance control of secondary cell, there is a method that uses a large number of transistors (TR) connected in parallel to each other; according to this method, we can control the charging speed by controlling the amount of current flowing into cells. As you can see from table VII, intelligent cell balance method confirmed to be the most effective method since maximum power and each cell's voltage differences are minimized; the intelligent method performance increases the power usage in 1.71 % (from 97.43 % to 99.14 %) and decreases the cells voltage declination in 3.76 % (from 5.95 % to 2.19 %).

Hybrid Electric Vehicles (HEV) or electrical cars require much power; therefore, tens of cells are linked by series inside the system. In this case, we can ascertain that intelligent control method becomes the most effective balancing method.

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