A PWM Controlled Simple and High Performance Battery Balancing System

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Abstract-- **For balancing battery cells connected in series string, a simple and high performance battery balancing system is proposed. In this system, technique of DC to DC converter with PWM control is used for balancing all cell voltages completely. The switching surge and noise are made small by soft switching with inductor commutation. This system is suitable for electric vehicle, handy-type personal computer, UPS and so on.**

I. Introduction

For a power source of usual electronic devices such as UPS and the electric vehicle, the battery made of serially connected multiple cells is generally used. In this case, if there are some unbalances among cell voltages, the total lifetime and the total capacity of the battery are limited to a lower value. To maintain a balanced condition in cells, an effective method of regulating the cell voltage is indispensable. For this purpose, battery management systems have been presented [1][2][3][4]. However, each of these systems has merits and demerits on the accuracy, the cost, the size and the efficiency and so on. Especially, these systems don't always equalize all cell voltages. In the method presented in this paper here, a complete balancing is possible by technique of DC to DC converter with PWM control, where, cell voltages are controlled by a means of the PWM from signals of differences in respective cell voltages through the battery management system. Further, the switching noise and switching loss in this system are made small by the soft switching using a reactive current of choke coils, so called inductor commutation.

II. Conventional Battery Cells Balancing System

Fig. 1 (a) shows a typical method for battery balancing system using the dissipation in the resistance [1]. In this system, any cells reached to a reference voltage with a sign of full charge are bypassed through the resistances and transistors in the active region. But this method is defective due to a loss in the resistances or the transistors. Therefore large radiators are needed to remove the heating. Further, an unbalance during discharging can not be compensated in this system. Fig. 1 (b) shows another example of balancing the cell voltages using the capacitors switched to the other cell [2]. In this system, capacitors C1 and C2 are connected through switches S1~S3 or switches S1'~S3'. Switches S1~S3 and switches S1'~S3' are switched alternately. Therefore, each cell's voltage is clamped each other through each capacitor so that all the battery cells may be balanced. As the key point of this system, control currents flowing between the cells and the capacitors are limited in the internal resistances of the respective cells and the another components, because the control current is supplied by voltage difference between the cells and the capacitors. Moreover, the operation of this system based on balancing between neighboring cells. Therefore all cell may not be equalized completely. On the other hand the system shown in Fig. 1 (c) and (d) are for self-balancing, where voltage are balanced using magnetic coupling [3] [4]. In these circuits, all battery cells are balanced through

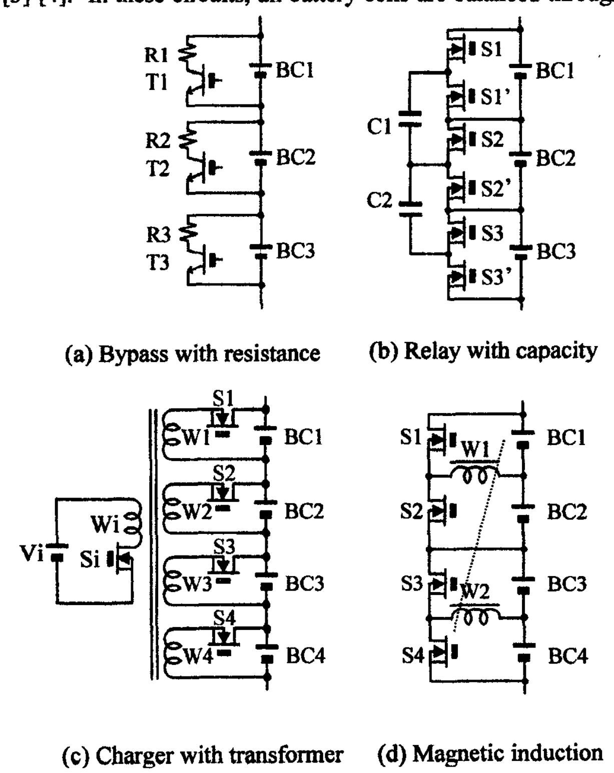

Fig. 1 Conventional battery sells balancing system.

an induction between multi-windings of the transformer. However, in these circuits, it is necessary to do a complete coupling among windings. And the control current flowing between the cells and the windings is limited in internal resistances of the respective cells and the other components.

III. PRINCIPLE OF PWM CONTROLLED BATTERY BALANCING SYSTEM

Fig. 2 shows a circuit to explain the basic principle of the method presented here, where two cells are balanced by means of PWM. The method is the same as that of a technique of DC to DC converter with duty ratio control. In this system, two cells BC1 or BC2 are connected to alternately a choke coil L through switches of complimentary pair. Fig 3 shows switching scheme of this system. In these waveforms, the action of soft switching is neglected to simply the explanation. For driving the complimentary pair switch, an oscillator supplies the square wave with 50% duty as shown Fig. 3 (a). Then PWM control is achieved independently in each switch using variable resistances RC1 and RC2 controlled by a battery management system (BMS). For example, if the voltage V1 of the cell BC1 is higher than the voltage V2 of the cell BC2, a variable resistance RC1 is increased by BMS. Then the voltage waveform supplied to the gate of the complimentary pair switch, which draws a transient as shown in Fig. 3(b). Therefore, on time of the switch S1 and off time of switch S2 being extended as shown in Fig. 3 (c)(d), an average current flowed into the cell BC2 is shifted to positive side as shown in Fig. 3 (e). In the same way, if the voltage V2 is higher than the voltage V1, a variable resistance RC2 is increased, an average current flowed into BC1 is shifted to positive side. Finally, if the voltage V1 equals to the voltage V2, both variable resistances are changed into highest resistance, then the complimentary pair switch is made to be off. Therefore, there is no power loss.

In the conventional system as shown in Fig.1 (c), just after the switches turn off, a large surge voltage arises due to energy stored in the leakage inductance of the transformer during the switches on. For protecting the switch against the surge voltage, a snubber is usually necessary. It will cause a loss in the resistance component of the snubber. In the proposed system as shown in Fig. 2, a surge voltage does not occur by making use of soft switching. This technique is easily achieved by setting in short off interval (dead time) during commutation of the complimentary pair switch. In the dead time of the commutation from the switch S1 to the switch S2, the magnetic energy stored in the choke coil is recovered to the cell BC2 through the body diode of the switch S2. At the same time, the surge voltage is reduced. In addition, a charge stored in parasitic capacitance of switch S2 being also recovered to BC2, the voltage of switch S2 is changed to zero. Because the switch S2 is turned on in this interval, the switching loss is reduced. In the same way, surge and switching loss are reduced during the commutation from the switch S2 to the switch S1.

Fig. 4 is an example for realizing a battery balancing system controlled by PWM, where series connection of 5 cells

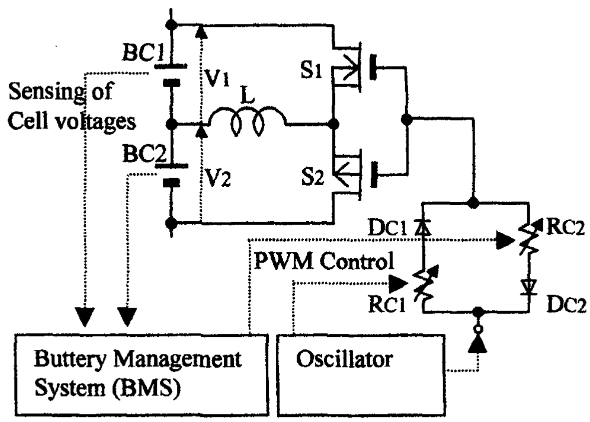

Fig. 2 Principle of PWM controlled battery balancing system

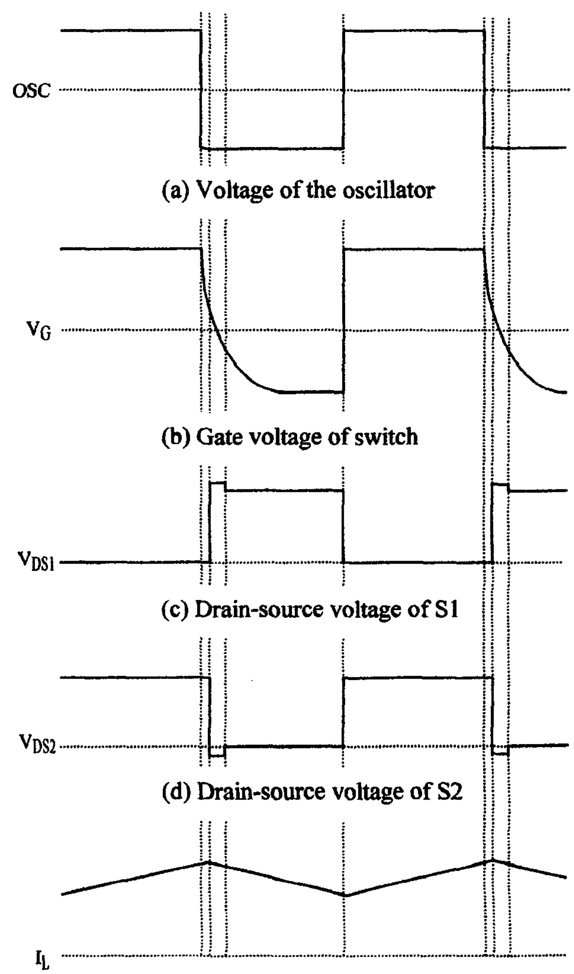

Fig. 3 Switching scheme in case of V1 > V2

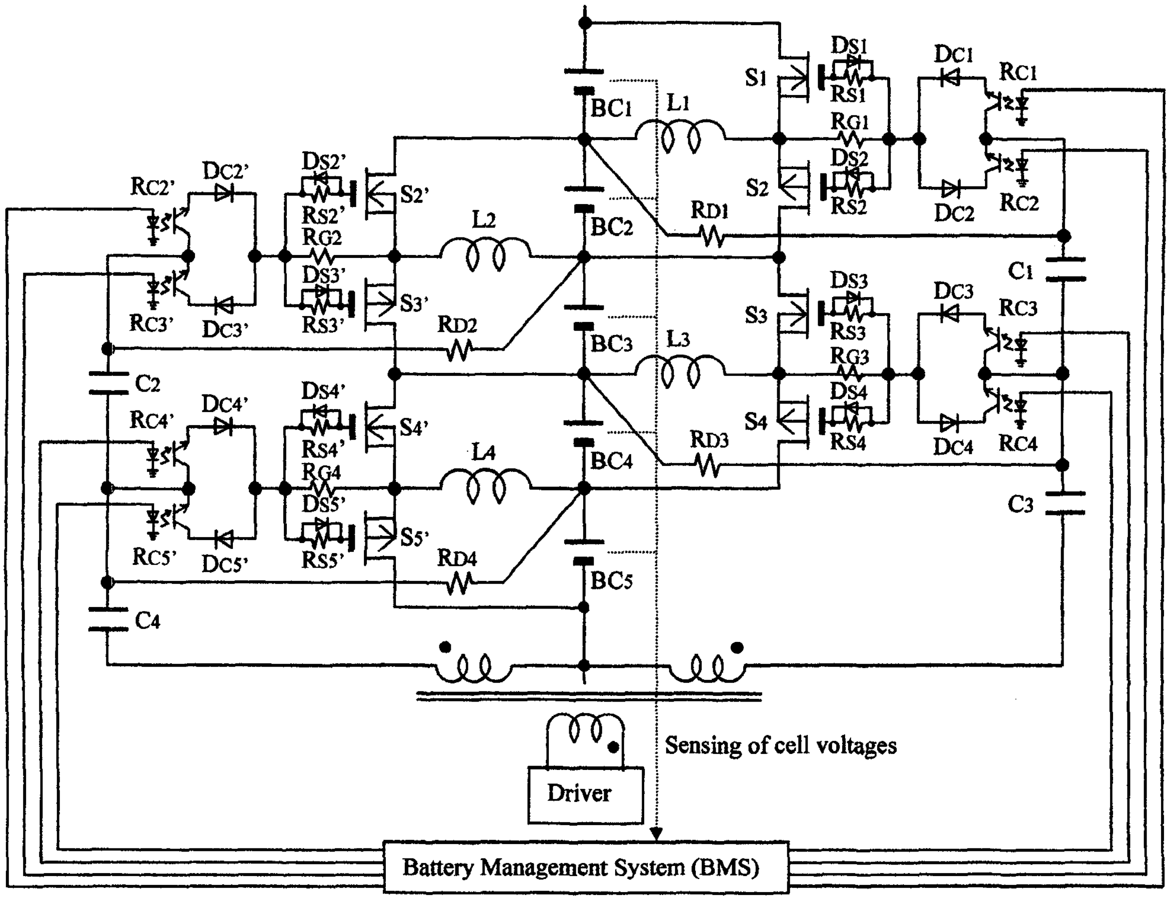

Fig. 4 Example of PWM controlled battery balancing system

is examined. In this system, variable resistances are replaced with photo-transistors for the isolation of the signal from BMS. Resistances RS1, RS2, RS3, RS4 and RS2', RS3', RS4', RS5' and Diodes DS1, DS2, DS3, DS4 and DS2', DS3', DS4', DS5' are used for making a small dead time in order to have a soft switching. For driving of all complimentary switches by a single driver, small capacitors C1, C2, C3, C4 are connected to battery cells in parallel through resistances RD1, RD2, RD3, RD4. RG1, RG2, RG3, RG4 are bias resistances of the complimentary pair switches.

IV. Experimental Results

TABLE 1
Value of Parameters

Symbol	Value
L	100 μH
C1, C2, C3, C4	0.1 μF
RD1, RD2, RD3, RD4	100kΩ
RG1, RG2, RG3, RG4	100kΩ
RS1, RS2, RS3, RS4 RS2', RS3', RS4', RS5'	25Ω

For the experiments, the circuit parameters of this system are given in Table 1. Fig.5 shows a simplified block diagram to evaluate the operation of the circuit shown in Fig.4. BC1, BC2, BC3, BC4 and BC5 are lithium-ion battery cells of 3.6V, 1350mAh. Current source 1A is used for testing the characteristic when a switch S is connected to the terminal 1. Resistance 17Ω is used for testing a load characteristic when the switch S is connected to the terminal 2. The battery

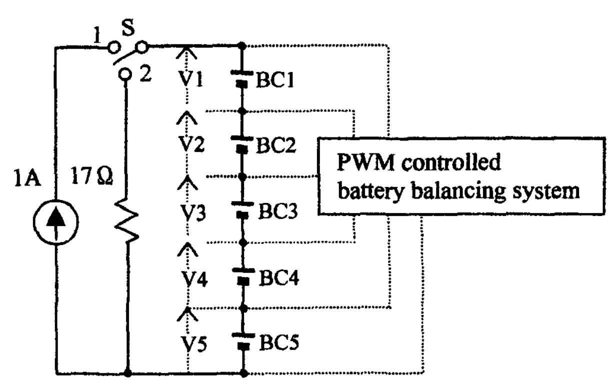

Fig. 5 Experimental circuit for cell's balancing.

balancing system is driven by a frequency of 100kHz. Fig. 6 (a) (b) shows experimental results of charging characteristics. In this experiment, initial voltages of BC1, BC4 and BC5 are equal to 3.5V as a full discharged condition, and initial voltages of BC2 and BC3 are equal to 4.0V as a half discharged condition. Fig. 7 (a) (b) shows load characteristics. Also in this case, when a test starts, initial voltages of BC2 and BC3 are equal to 4.3V as a full charged condition, and initial voltages of BC1, BC4 and B5 are equal to 4.0V as a half discharged condition. Fig. 7 and 8 shows that the cell's voltages are completely balanced by the novel balancing circuit proposed here.

V. CONCLUSION

In the preceding discussions, we have proposed a novel balancing system for improving the battery lifetime and the performance, and verified the usefulness by the experiments on the charging and discharging characteristics. This system consists of same numbers of DC to DC converters as that of the cell, all cell voltages are completely balanced by PWM control. This system is simple construction because all converters are drove by an oscillator, and PWM controls of respective converters are given by a battery management system. Also high efficiency is realized by making use of soft switching. The number of DC to DC converter will be reduced by using time sharing method.

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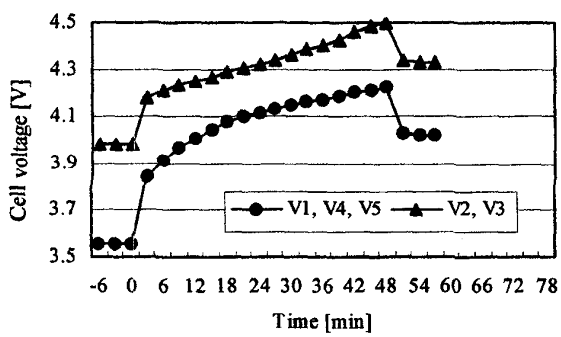
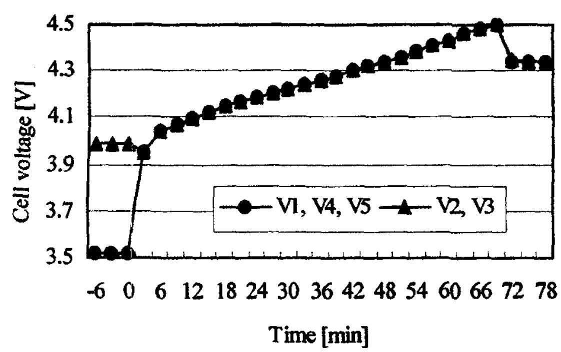
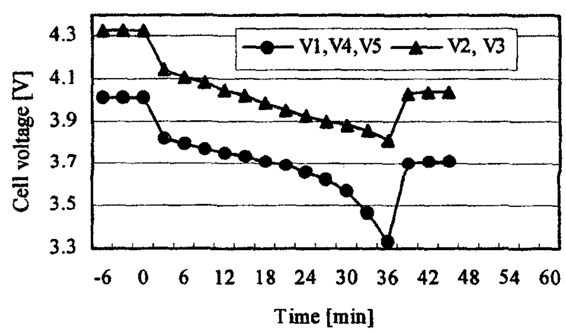


(a) Without battery balancing system

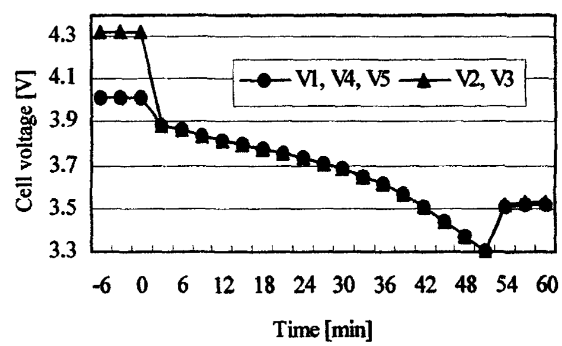


(b) With battery balancing system

Fig. 6 Charging characteristics



(a) Without battery balancing system



(b) With battery balancing system

Fig.7 Discharging characteristics