Temperature-compensated Overcharge protection Indirect measurement circuit

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Abstract— Existing BMS have measured the voltage of each cell of the battery through physical connection between the battery and the control unit. However, it was found that if a battery fire occurs and an external damage is applied to the battery, the BMS to protect the battery is destroyed. Therefore, in this paper, a system was proposed and implemented using an indirect measurement technology that can monitor the voltage of the battery without physical connection between the BMS and the battery. The physical connection between the battery and BMS was disconnected by configuring a closed circuit of battery and LED and measuring the voltage according to the brightness value of LED, and the accuracy and temperature compensation circuit were resolved by installing a reference LED(Ref. LED). In addition, power consumption was greatly reduced by using the subthreshold of the LED. It was verified that the voltage measurement error of the system implemented in this paper is 1 mV or less and the power consumption is 200μW to 360μW.

Keywords—BMS; Voltage Measurement; Indirect measurement Wireless;

I. Introduction

Recently, with the development of battery technology, various fields such as uninterruptible power supply (UPS), energy storage system (ESS), and electric vehicle are used, and the demand for systems using lithium-ion batteries is increasing rapidly. Accordingly, demand for Battery Management System (BMS), a system with functions of controlling and protecting batteries, is increasing [1]. However, battery fires have recently attracted many issues. Battery fire is being caused by various causes, such as temperature and humidity of the surrounding environment, battery fire caused by overcharging, etc[2]. However, most of the causes are that the control unit could not serve again by being destroyed because the overvoltage of the battery affects the control unit that uses the low voltage, resulting in a fire in the battery. The representative function of BMS is to monitor the voltage between the cells of the battery to support the overcharge protection function and to safely perform charging and discharging through battery cell balancing. However, it is reported that the control unit is destroyed due to the imbalance between a battery capable of exhibiting 600V or higher and the control unit operating between 24 and 1.2V, and a fire accident occurs in the battery due to BMS failure. As a fundamental solution to this problem, a new BMS system that supports safe overcharge protection monitoring system operation by isolating the high-voltage battery and the control unit is proposed. figure 1 shows the overcharge protection system of the existing battery system.

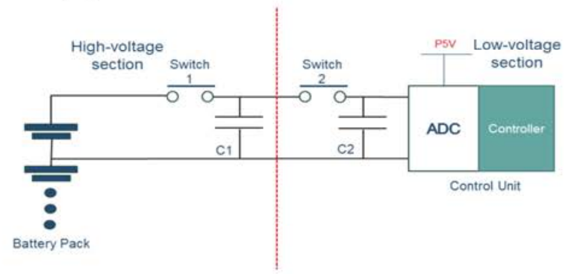

Figure 1. conventional battery overcharge monitoring system

For voltage measurement in the structure shown in Fig. 1, Switch 1 is closed to charge C1, Switch 2 is closed to charge C2, and then the voltage is measured by ADC in the control unit [3]. In the case of this measurement method, if a problem occurs in a high voltage part including a battery pack, the insulation is destroyed in a low voltage part. When a defect occurs in the battery system, the insulation of the BMS power, which performs the function of protecting the battery system, is destroyed, failing to function as a BMS and being destroyed. Therefore, a circuit for monitoring the battery voltage without physical connection between the control unit and the battery pack is required. This paper proposed and implemented a circuit to monitor the voltage between battery cells while separating the high voltage part and the low voltage part by applying an indirect measurement technology that measures the voltage without physical connection between the control unit and the high voltage part.

II. Indirect Measurement Technology

A. Sub-Threshold region operation for saving Energy

The battery voltage measurement technology operates using battery power, so high power consumption leads to performance degradation of the battery. Therefore, due to the

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nature of indirect measurement technology that constitute closed circuits at all times, there is a need to reduce power consumption. Therefore, this paper proposes to use the subthreshold of the LED as an operation to reduce power consumption of the indirect measurement technology. The subthreshold refers to a phenomenon in which a current flows finely even though a voltage smaller than the threshold voltage is applied. There is a current characteristic curve in which the brightness of light of the LED is proportional to the current and changes according to the applied voltage. The general LED usage period is after the threshold voltage, and current consumption is large. However, it was confirmed that a leakage current occurred even in a low voltage section of 0.7 V or less, and thus, current consumption was low and LED was emitted. Transistor is a well-known technology and is being used as a technology called subthreshold swing. In recent studies, studies on the analysis of low-power CMOS inverters are also underway [4]. The current–voltage graph of the LED is shown in figure 2.

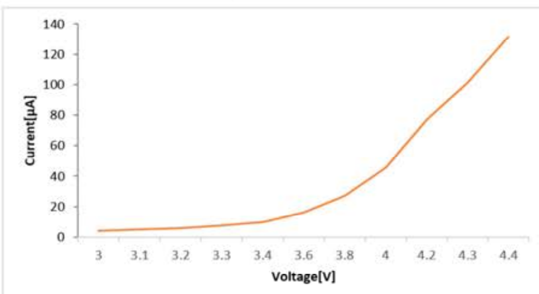

Figure 2. LED Current – Voltage Graph

B. Voltage measurement method

In this paper, an indirect measurement technology for measuring a voltage through a medium without physical connection between a battery pack including a high voltage part and a control unit is proposed and implemented. The indirect measurement technology is a technology for detecting and measuring a change in the voltage of a battery by detecting a change in the brightness of an LED. To this end, the light of the LED was not emitted through the light blocker, and the light was measured using a photo sensor. figure 3 shows the block diagram of the indirect measurement technology.

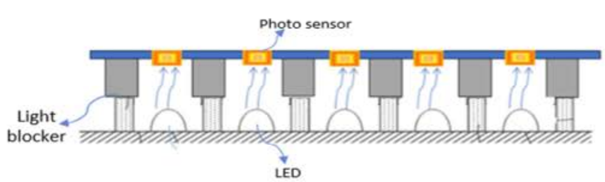

Figure 3. Schematic diagram of indirect measurement technology

Generally, lithium ion batteries are known to have an operating range of 3V to 4.3V. However, measuring a voltage using the indirect measurement technology of this paper requires an alternative because the lithium-ion battery and the operating voltage do not match. Therefore, in this paper, an indirect measurement technology using a diode array to lower the voltage of the battery and thereby change the brightness of the LED was implemented. figure 4 shows a conceptual diagram of implementing an indirect measurement circuit using a Photo sensor.

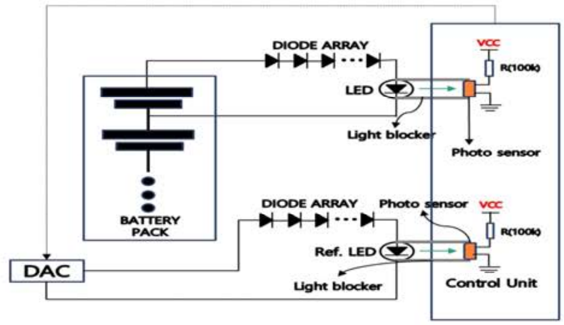

Figure 4. LED-mediated indirect measurement circuit

As shown in figure 4, the LED connected to the battery is transmitted to the photo sensor through the light block. The resistance value of the photo sensor varies according to the brightness of light. The indirect measurement technology proposed in this paper is a method of measuring voltage using a other medium, so a reference is required. In this paper, as illustrated in figure 4, a digital to analog converter (DAC) that outputs a voltage value input into a program as a reference. The voltage value was obtained through the reference LED(Ref. LED) by the photo sensor and used as the reference voltage. Using this, the voltage is calculated by comparing the brightness value of the LED connected to the battery pack. Reference voltage is obtained from DAC. The voltage-brightness graph of the LED is shown in figure 5.

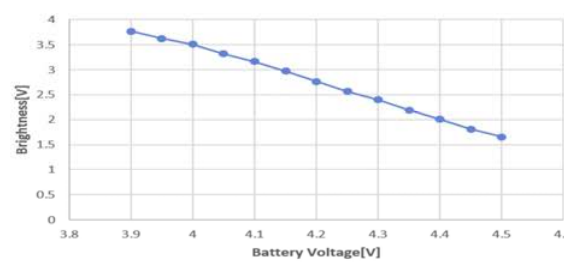

Figure 5. Brightness - Voltage Graph

C. Temperature Countermeasure

Due to the nature of the system that uses LEDs and photo sensors operated based on the subtreshold region, it is inevitable to be sensitive to temperature. In this system, the LED brightness value changes according to temperature at the same battery voltage. Therefore, appropriate temperature compensation measures are needed. The temperature characteristic graph of the LED is shown in figure 6.

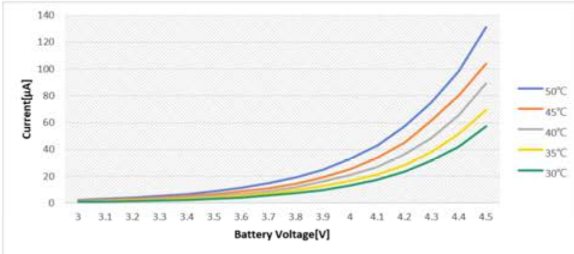

Figure 6. Changes in Current According to Temperature

III. CONSTRUCTION OF EXPERIMENTAL ENVIRONMENT

The designed indirect measurement system is shown in figure 7. The board in figure 7 is named overcharge protection board. The structure in figure 7 is a system configured by blocking light using a light blocker on 20 LEDs installed in the control unit, coupling a photo sensor substrate thereon, and coupling a diode array substrate to the control unit. The board shown in figure 7 is designed to measure the voltages of a total of 20 battery cells. The micro controller unit(MCU) of the control unit stores the look-up table for LED brightness and voltage.

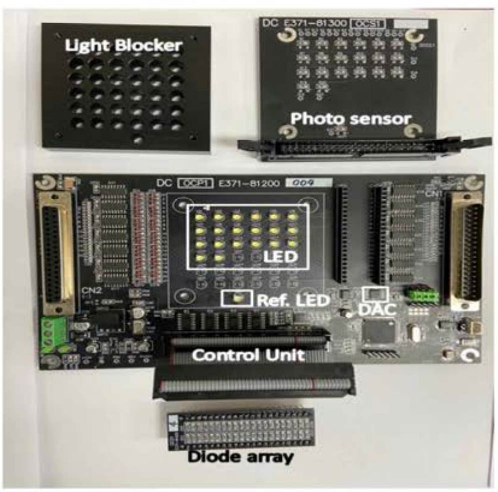

Figure 7. Designed Overcharge Protection Board

Table 1 shows the average of the measured values more than 10 times by applying a voltage from 3.9V to 4.3V to the LED channel of the designed overcharge protection borad. It was confirmed that all battery cell measurement voltages have an error value of 1 mV and a power value of about 200 μW to 360 μW even at a change of 30°C to 50°C. In addition, the results of comparison with other papers are shown in Table 2. Table 2 implements accurate measurements with low errors and low power consumption along with temperature compensation circuits. In the case of [6], voltage measurement technologies in isolation were compared even though they were other applications than the voltage measurement method used in BMS. In the case of [6], voltage measurement was performed without physical connection using a wireless transceiver, and the indirect measurement method proposed in this paper was to measure the voltage using the brightness of the light of the LED.

TABLE I. RESULTS OF OVERCHARGE PROTECTION BOARD

Battery voltage[V]	Results of overcharge protection board			
	Measured voltage[V]	*Error[mV]*	*Power[μW]*	*Current[μA]*
3.919	3.918	1	211.905	54.067
3.971	3.970	1	219.975	55.400
4.022	4.021	1	231.112	57.467
4.071	4.070	1	244.936	60.033
4.103	4.102	1	254.523	62.033
4.174	4.173	1	282.696	67.733
4.204	4.203	1	298.204	70.933
4.272	4.271	1	341.333	79.900
4.290	4.289	1	355.669	82.900

TABLE II. RESULTS OF COMPARISON WITH OTHER PAPERS

Paper	Results of comparison with other papers			
	Error	*Power*	*Temperature compensation*	*physical connection*
[5]	40~30[mV]	Not considerd	-20°C ~ 40°C	o
[6]	5[%]	Not considerd	Not considered	x
This work	1[mV]	200μW ~ 350μW	20°C ~ 50°C	x

IV. CONCLUSION

This paper proposed and implemented an indirect measurement technology that measures a voltage without physical connection between a battery pack and a control unit. The implemented system can measure the voltages of a total of 20 battery cells and much lower the power usage using the subthreshold region. It was confirmed that the voltage measurement error was 1 mV or less even with temperature changes and that the system uses the low power consumption of 200μW to 360μW of power. Especially in this paper, a solution to the error according to temperature was presented using an reference LED with DAC.

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