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Introduction to the Second Generation Battery Control Unit

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Abstract

Recently, various types of lithium ion batteries and similar electric storage devices have appeared on the market. These electric storage devices combine anywhere from several cells for 24 V, up to over a hundred cells for voltages as high as 400 V - to create power systems for various industrial fields.

These power systems need to

1) come in various sizes,
2) provide absolute safety,
3) performance,
4) be compatible with the devices they are used in (communication).

Achieving all four of these points simultaneously requires a deep knowledge of electric storage devices. It also requires technology that provides a high degree of control.

PUES Corporation puts effort to develop intelligent control devices that allows for the power system to be constructed easily while avoiding the need to specify the electric storage device.

A BCU (Battery Control Unit) is indispensable for constructing power systems that combine several electric storage devices, such as lithium ion batteries. This paper introduces PUES Corporation’s Second Generation Battery Control Unit, which has the following characteristics:

(1) A modularized power system that is suitable for systems of various sizes
(2) Intelligent protection control technology developed for electric storage devices
(3) Control technology that extracts maximum performance from electric storage devices
(4) An enriched interface, courtesy of external equipment and CAN communication

Keywords:
Lithium ion baterry, BCU, BMU, Battery control, Battery management

1 Specification

1.1 Configuration

Typically, multiple batteries are serially connected to form a unit module, and the necessary number of modules is stacked to construct the battery system. Fig.1-1 shows a system that was developed by PUES. The module is based on 24 V, and 8 cells form a unit that is able to apply to the iron phosphate Li-ion battery that has recently drawn attention for its safeness benefits. The Battery Management Unit (BMU) contains maximum of 12 Battery Scan Unit (BSU) that correspond to each module. It communicates with the BSUs and the charger via CAN. The BMU controls communication with the upper controller and also provides the control function for the main relay and the pre-charge relay that comprise the Junction Box. The BCU is the integrated system including the BMU and the BSU.

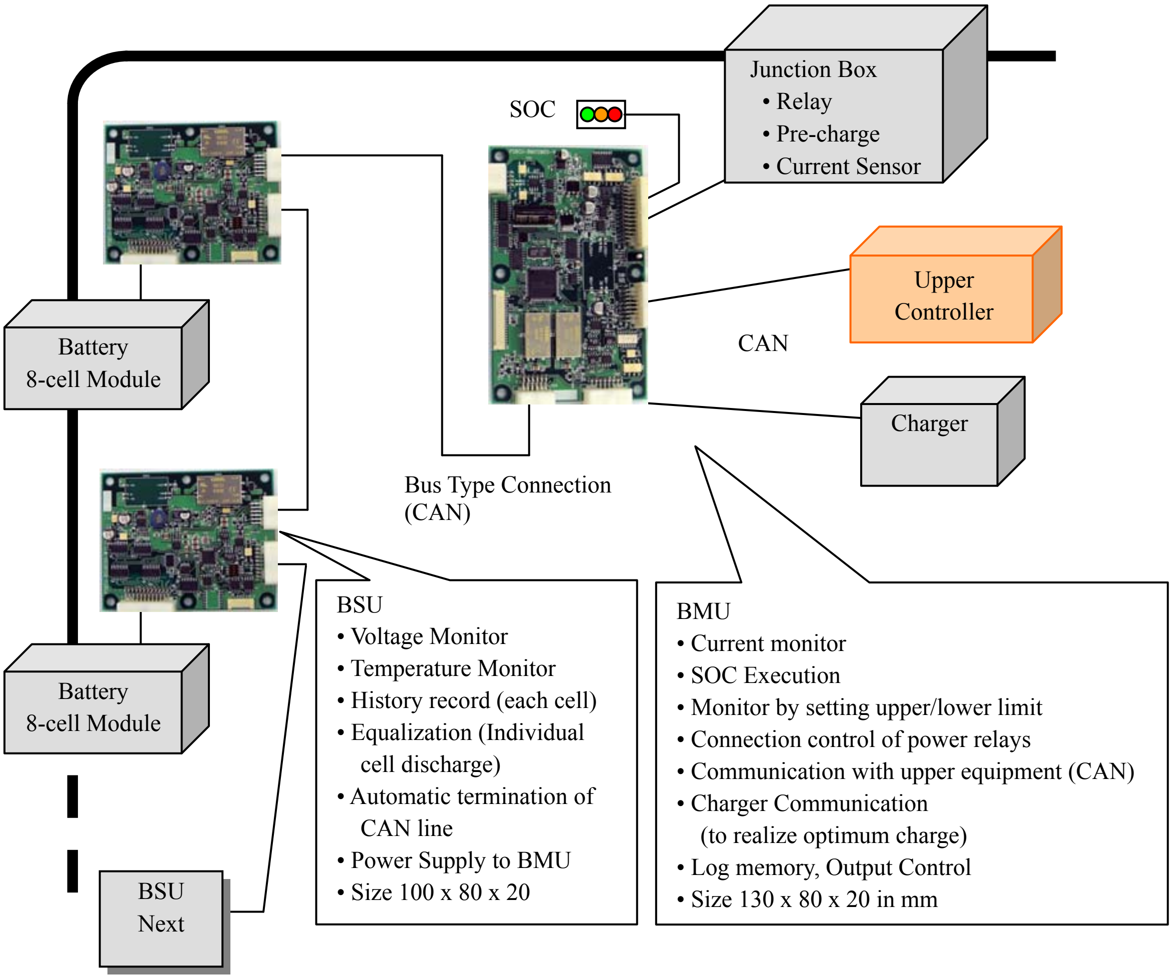

Figure 1-1: BCU Configuration

1.2 Hardware Basic Specifications

Table 1-1 shows the basic specifications of the BCU hardware developed by PUES.

Table 1-1: Basic Hardware Specifications of BMU and BSU

BMU Hardware	Specification		Remarks
CPU	M306NKFH	Renesas	
Number of BSU connections	Max. 12		
Power ON start port	2	Loop 1, Current 1	For discharge, for charge
Input port	5		Loop 4, Current supply 1
Current sensor input	1	5±2 V Input	5 V/12 V Sensor power supply possible
Output port	3	For relay/FET control	24 V/200 mA
Output port	3	LED Drive	For SOC display, etc.
Communication port	2	CAN B Ver.2	500 kbps
Circuit Power Supply	Battery Module		BSU linkage } Select
	External 12 V		
Power Consumption	5 V 350 mA or less	In operation	
	5 V 0.1 mA or less	In sleep	
Dimension	130 x 80 x 20	in mm	
Operating Temperature/ Humidity	-10 – 60°C	90% RH	Without condensation

BSU Hardware	Specification		Remarks
CPU	R5F2123	Renesas	
Input Voltage Range	10 – 36 V		
Cell Number	4 – 8		
Cell Voltage	1.5 – 4.3 V		
Temperature Measurement Point	5		One Point on board, fixed
Temperature Measurement Range	-10 – 85°C		
Voltage Equalizing	Resistance Discharge Method	80 mA @ 4 V	
Communication port	1	CAN B Ver.2	500kbps
Circuit Power Supply	Battery Module		} Select
	External 5 V	Supplied by BMU	
Power Consumption	5 V 150 mA or less	In operation	
	5 V 0.1 mA or less	In sleep	
Dimension	100 x 80 x 20	in mm	
Operating Temperature/ Humidity	-10 – 60°C	90% RH	Without condensation

1.3 Functional Specifications

Table 1-2 shows the functional specifications of the BCU. The function of this BCU comprises data exchange between the BMU and the BSU wherein the data is obtained individually.

Table 1-2: Functional Specification

BCU Function	Specification		Remarks
Cell Voltage Upper Limit Monitoring	4.2 V	±0.02 V	Setting modifiable Max.4.35 V
Cell Voltage Lower Limit Monitoring	2.5 V	±0.02 V	Same as above, Min.1.5 V
Abnormal Voltage Variation Rate	–		According to discussion
Module High Temperature Monitoring	60°C	±1°C	Setting modifiable Max.85°C
Abnormal Temperature Variation Rate	–		According to discussion
Discharge Current Monitoring	–		Same as above
Charge Current Monitoring	–		Same as above
Voltage Equalizing	Convergence 25 mV	Start 40 mV	
SOC Execution Report	Report Precision 20%		Target Precision 5%
SOC Display	High/Middle/Low SOC	3 LED Displays	Option
Power ON/OFF Control			Relay Sequence Control
Degradation Progress Suppression			Avoid High Voltage Storage/Low Voltage Operation
Cell Management			Historical Record
Cell ID Management			Currently under discussion with battery vendors
Upper Controller Communication			Start/Stop Command Receipt, SOC Provision Notice of Alarm and Fault etc.
Charger Communication			Rapid Charge, Charging Time Setting etc.
Logging			According to discussion

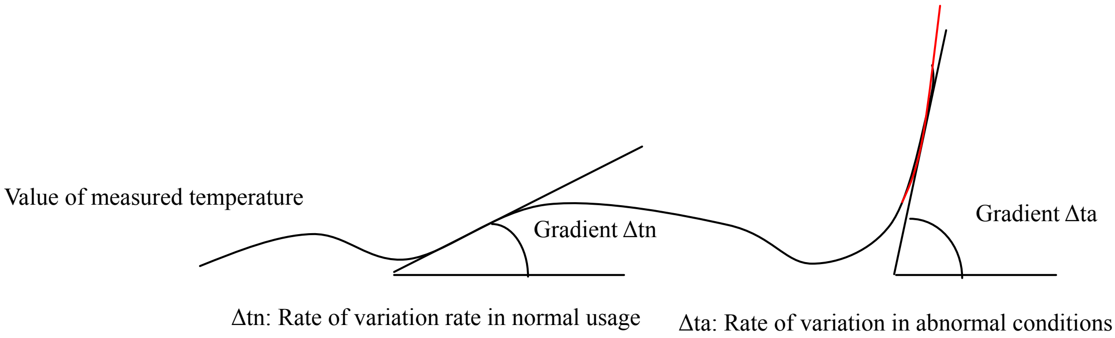

Figure 2-1: Detectionof dynamic variation

2 Function

2.1 Battery Protection Function

The upper and the lower limits of the three factors of voltage, current, and temperature, are monitored as essential conditions for protecting the battery. The following functions are incorporated as more intelligent approaches to dealing with these factors.

a) Detection of dynamic variations in the monitored object to improve the speed and the precision with which abnormalities are detected.

(1) Temperature: The temperature of a battery changes according to the charging and discharging operation, but variations over time can be estimated to some extent. Temperature variations under abnormal conditions are considered to be different than those under normal conditions. For this reason, temperature monitoring covers both the temperature variation rate over time and the upper temperature limit to provide early detection of abnormalities. The gradient of the temperature variations is monitored over time, as shown in Fig 2-1.

(2) Voltage: This consideration of the temperature is the same as the voltage. When an unexpected increase or decrease in the voltage is detected, even if the voltage is within the normal operating range, the battery is shut down or an alarm is issued to the upper equipment.

b) Inclusion of a function for logging the parameters and status to enable history management.
Among the various monitored data, that which is useful for the following purposes is sampled with appropriate frequency.

(1) For estimating the degree of degradation

(2) For maintenance

Data is logged for later use for maintenance.

Even if the battery is operated outside the upper or the lower limits of its operable conditions, this is allowed so long as such excess is within an allowable range and for a short time only. Intelligent management also enables, for example, the number of times the parameters enter this range to be counted. The accumulated count value can then be used for maintenance.

c) The power supply unit is designed for ultra-low power consumption, and includes an algorithm to prevent the full discharge of the electric storage device.
This BCU system receives the control power from each module and does not need an external power supply. The operating power supply of the system during sleep mode should be considered so it can perform important functions such as suppressing (i.e. equalizing) voltage deviations generated by charge/discharge or self discharge during operation. On the other hand, from the standpoint of battery usage, long sleep periods are often observed in the case of power tools, vehicles, and so on. If the control circuit consumes all of power and the battery fully discharges during this period, it is meaningless. Even the consumption of 5 V, 5 mA, if it continues for 1 week, will result in the consumption of 1 Ah or 5 Wh. The power supply developed by PUES has the following features.

(1) Uses an electric double layer capacitor (EDLC) for power supply control during sleep mode.

(2) The power is basically OFF during sleep mode but it wakes up periodically to monitor the battery.

(3) The wake up period is every 6 to 36 hours (variable depending on the EDLC selected).

(4) To provide this wake-up period, it has a clock that is powered by the EDLC.

(5) When the system wakes up, it fully charges the EDLC.

The power consumption is calculated by the ratio of the wake up period (3) to the charging time (5). According to data obtained by PUES, this ratio is equal to or greater than 1000:1 and the charging current is 100 mA with equal to or less than 5 V, and the average value is equal to or less than 0.5 mW. Even if we base our estimates on a DC/DC converter with efficiency as low as 50%, the power consumption in sleep mode over a period of one week is equal to or less than 168 mWh. Thanks to this EDLC and the clock, the macro-monitoring of the battery usage situation becomes possible. That is:

- The system identifies when battery is in long-term storage mode and measures the battery's voltage. When the voltage in the Li-ion battery is found to be inappropriately high for storage, the voltage can be decreased to the appropriate level by utilizing the equalization function to actively discharge the unit. This slows down degradation.
- Even if power consumption is low during sleep mode as described above, if the voltage decrease advances and approaches the voltage lower limit, it is possible to actively discharge the EDLC to stop the periodical wake up and lead to the full shut down of the power supply. The system ensures zero power consumption at low voltage levels.

2.2 Battery Control Main Function

a) High Precision Voltage Detection Circuit

Operational amplifiers are typically used for individual cell voltage detection in serially connected batteries. A switch is provided between the operational amplifier and the battery cell, and the operational amplifier is shared between cells to increase precision. An attenuator is inserted to keep the voltage in the measurable range when the voltage of the uppermost cell stage (viewed from the operational amplifier) of the serially connected battery is measured. The attenuator is the same for all cells and the battery load is kept constant. At the same time, the amount of attenuation in blocks is compensated by the operational amplifier. Fig.2-2 shows the output voltage of an operational amplifier that is measured using an analog switch to switch the voltage sources corresponding to the seven cells. Measurement errors are calibrated by measuring the known voltage.

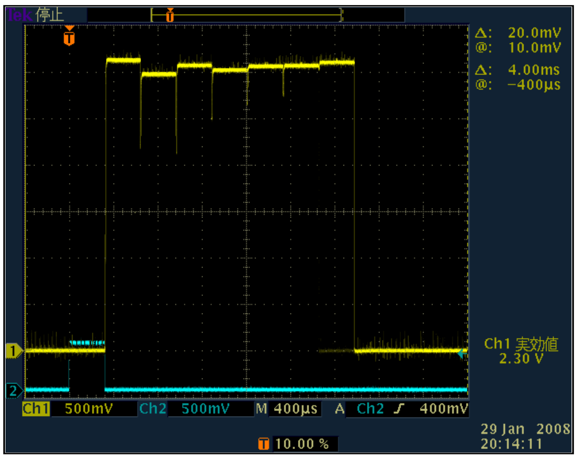

Figure 2-2: Voltage source wave form across seven cells

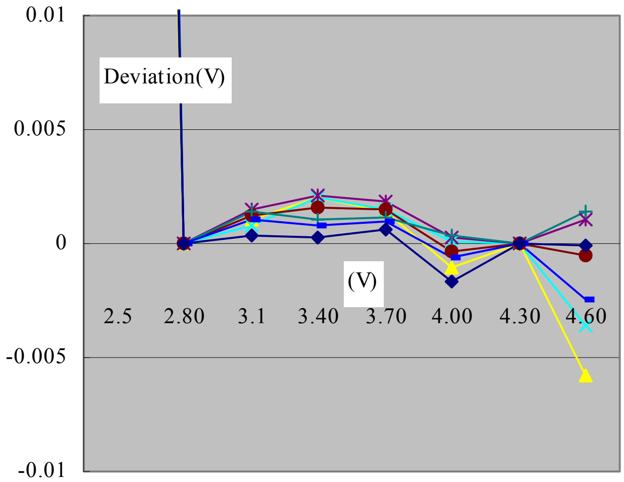

Figure 2-3: Deviation of voltage measurements after calibration (Valid range is 3 to 4.3 V)

PUES's BCU employs the resistance discharging method to save the circuit cost and achieve miniaturization. With the configuration shown in Fig.1-1, the voltage

resistance. However, the imbalance between the modules can not be covered by the BSU alone. In general, the BMU detects differences in voltage between the modules and forces the BSU of the module with the high voltage to discharge through resistance. But with the goal of efficient utilization of energy, we have developed a new method for suppressing imbalances by using the control circuit to consume excess energy in addition to achieving equalization through the resistance discharge method. This allows the unit to be used with systems with differing module configurations.

c) SOC execution

SOC execution, which is the main function of the BMU, is a complex process that uses current integration and calculated SOC from OCV. SOC calculation formula is obtained based on the measured value of SOC vs OCV characteristics preveusly. An appropreate SOC is estemated from these figures by various calculations methode, such as, replacement or a weighted average, dipending on the situations. The curve in Fig.2-4 plots the measured and approximated SOC vs OCV characteristics.

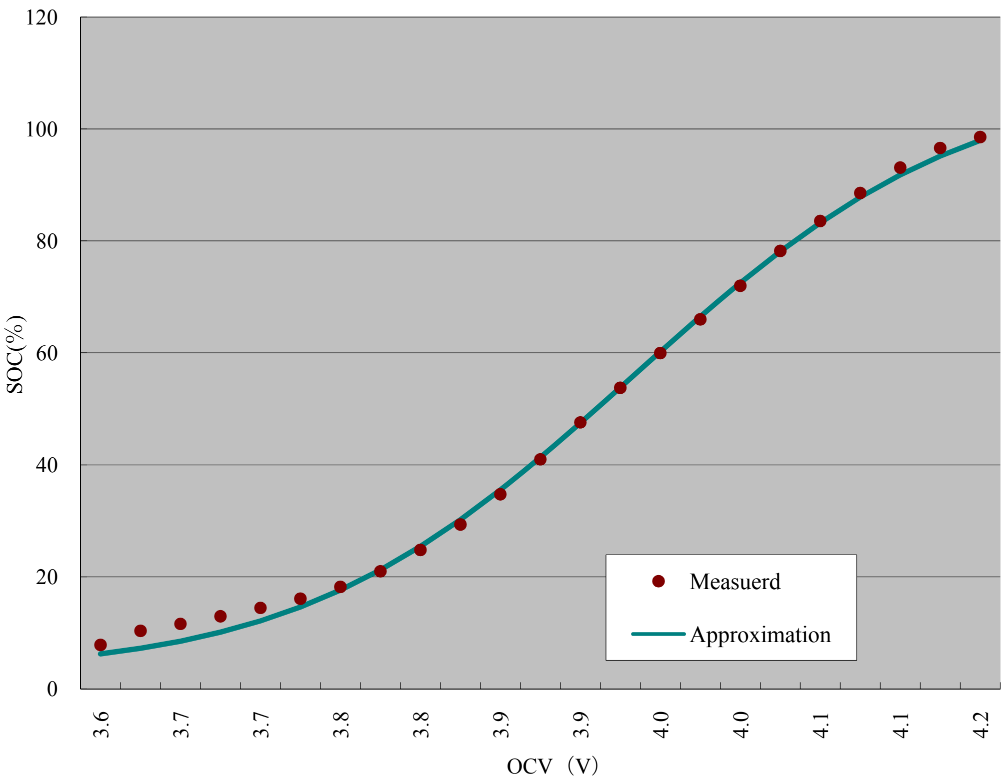

Figure 2-4: SOC vs OCV Characteristics(Measured/Approximation)

Fig.2-4 shows errors in the smaller SOC region but the approximate formula shows a lower value than the measured value. This provides a margin of safety for the customer.

2.3 Interface function

a) Hardware interface

An important consideration for the interface between the customer's circuit and the BCU is whether or not to insulate between the two components. We have prepared various interfaces that correspond to both situations. Details can be decided in consultation.

b) Communication interface (Conforms to CAN B Ver.2, 500 kbps)

This system has two communication systems. One is the connection to the upper controller and the other is the connection from the internal BSU to the charger. In large capacity battery systems, great consideration must be paid to reliability. Both communication systems employ a parallel type CAN that provides high reliability and strong resistance against noise. Details of the system can be decided in consultation.

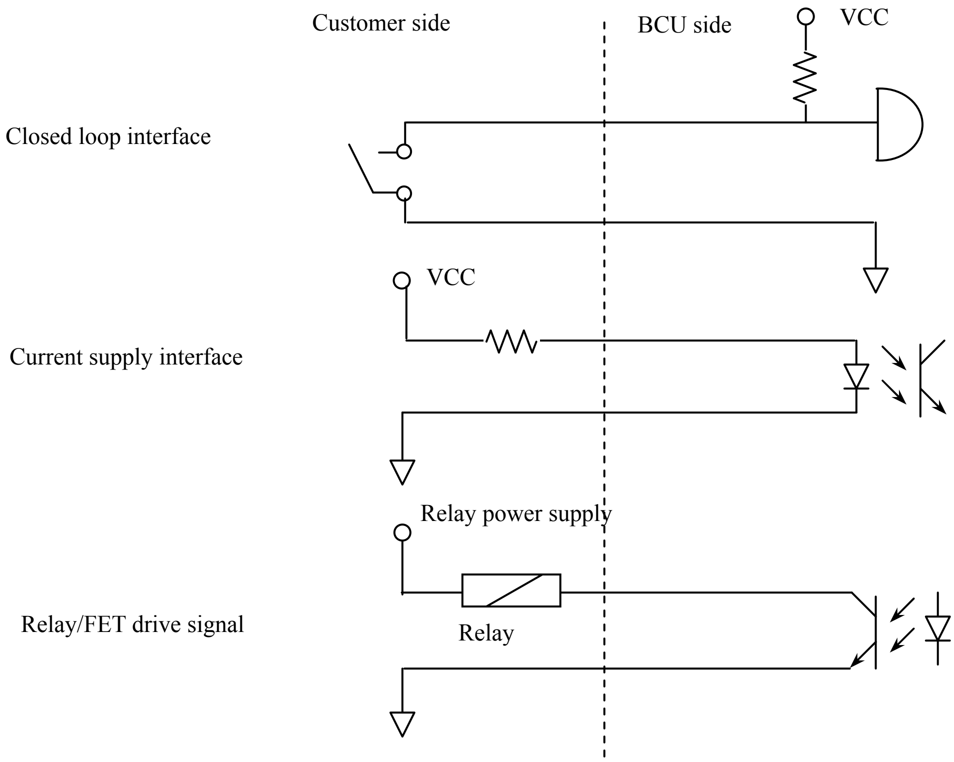

Figure 2-5: Examples of various interfaces

3 Summary

This system is the subject of many patent applications. Samples have been shipped to many customers and we are obtaining market results. In the future, we plan to add new functions, and the development of a third generation system with greater intelligence is being planned.

4 Authors

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2008 to present:
Executive vice president of PUES Corporation.
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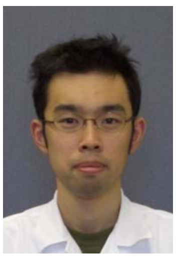

2006: Joined PUES Corporation