ANALYSIS OF MANAGEMENT SYSTEMS OF LITHIUM-ION BATTERY FOR EV / HEV

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Abstract: *In contrast to lead-acid battery cells in lithium-ion battery $LiFePo_4$ in serial connection can not be balanced with each other during the loading process. This is because the current stops flowing when the cell is full. This means that $LiFePO_4$ packs require management system (BMS}, because the proper electrical and thermal control of a lithium-ion traction battery consisting of many cells, divided into several modules, is imperative. During operation, voltage, and temperature variations in the cells may result in an electrical imbalance of the cell to the cell and cause a decline in the capacity of the entire set of cells of the battery by approximately 25%. In this work is presented and analyzed by the authors developed management system (BMS) of traction modular lithium-ion battery. This system shall keep under review, control and balance the battery balancing battery, based on current accurate measurements of cell voltage and active equalization parameters.*

KEYWORDS: *EV-electric vehicle, HEV- hybrid electric vehicle, MSB-monitoring status of battery, BMS - battery management system, SOC - state of charge, OCV - Open circuit voltage, ECU - electronic control unit, EQU - equalizer, CM - Central module, LM - local module*

1. Introduction Batteries connected in series in electric vehicles (EV) and hybrid electric vehicles (HEV), require monitoring equipment (MSB), which is able to measure the voltages of the individual modules (several cells connected in series) to prevent damage and to identify defective elements [7]. As stated in [5,7,9], almost all types of batteries can be damaged by excessively high or low voltages, and in some cases the results can be disastrous. Lithium-ion cells, for example, can catch fire if an overcharge of ultra high voltage.Therefore, after having been identified high or low voltage in some cells, a smoothing process must also be used for re-balancing the voltages. Imbalances are particularly prevalent in EV and HEV, since batteries are often dynamically loaded or discharged. Some problems associated with the measurement of these voltages are also described in [9], with the possible solutions.

2. Purpose of work

To analyze the conditions and technical parameters of existing systems for battery management. On the basis of this analysis was to develop a new technology to reduce costs and improve safety and efficiency of the management of the battery in order to make it suitable for practical EV and HEV. To build and test an engineering prototype that uses these new technologies. To present the approach and results of the study and research of the developed module system for the management of batteries for EV and HEV.

3. System requirements

Li-Ion battery has strict management requirements because it can ignite if supercharged. This problem is particularly acute for large battery packs in EV and HEV, when supercharging can cause a fatal accident. To ensure safety, the voltage of each Li-Ion cell must be measured very accurately, since it is the best indicator of SOC [5,8]. This means that quite a large number of measurements of the voltage to be processed in each measurement cycle, for example 32 cells every 2 seconds. Balancing (equalization) of the cell voltages is also more difficult because a simple method for recharging a low current (trickle charge) can not be used. Instead, the cells must be individually balanced, with an electric circuit, for example with equalizer to the system. Abnormal conditions in the cells for voltage, current and temperature of the battery to activate the alarm and be handled promptly. As the safety of the battery depends on the management system (BMS), the reliability of the control system becomes very important. Therefore, safe use require different hardware and software applications to ensure safe use and protect the battery in case of failure. It is also very important to control the cost of adding additional features and improvements to existing features. In addition, the size and weight must be minimized in order to allow the BMS to fit in a compact box of the battery. A block diagram of a typical control system includes a battery electronic control unit (ECU), which monitors the real-time status of the battery system and equalizer (EQU), which balance the levels of charge of the battery cells [1,2]. The operation of ECU has four functions: data acquisition, data processing, and data transmission control. ECU usually measured voltage of all cells, a few selected temperatures and current of the batteries, monitors the battery status (MSB). It then analyzes the data and extract information about battery protection and determining the state of charge (SOC). Some information is also transmitted to the rail with the vehicle data. ECU controlling certain types of equipment, maintenance of the battery as the battery cooler, heater, EQU, switch automatically disconnect (breaker) and the ability to manage on-board charger. The purpose of EQU is to minimize the SOC differences between the cells of the battery, as such imbalances would reduce the usable capacity of the battery. However, the batteries in EV and HEV are often recharged and when released from control, tend to imbalance. An EQU maintain balance in the cell or by loading the cells or by poor aligning with normal cells. The old design of BMS usually takes volume as a whole battery module [3,4]. This kind of a BMS is a cost-effective, because it requires significantly less components and is less complex in terms of data processing and communication. However, it does not offer the ability to measure and balance individual cells or modules in the package. For more volatile Li-Ion batteries with cells with larger tolerances each cell must be measured and balanced [5].

4. Analysis of existing systems for battery management

Several modular system BMS for large batteries are already commercially available. [5] Some battery

ISSN 1310-3946

manufacturers have designed systems specifically for their own batteries [5,9]. A review of these projects shows that, while undoubtedly functional, they do not give certain qualities demanded by modern EV / HEV batteries. Some of these functions are very critical and need new technologies. Some of these BMS are unable to determine the SOC, so it will not be possible to keep the SOC within the desired range, and the user will not know the remaining battery life. To determine the SOC, BMS requires accurate measurement circuit is loaded and complex algorithm which is designed with knowledge of the electrochemical characteristics of the battery. Measuring the voltage is another problem for many of these earlier systems. First, the accuracy is not sufficient for Li-Ion battery, and this may affect safety or reduce the usable capacity of the battery. Furthermore, the period of time between each measurement of the voltage in each cell is so long that the current battery status may change significantly over this time period. As the battery voltage changes with current, this would distort the measurement data of the voltage. The communication circuits in any of these systems are also questionable. Many systems use the RS232 bus for transmitting data that does not have sufficient power handling capability for errors. Possible communication errors or failures can cause serious problems with safety. Current balance can be dissipative (passive) or undisspative (active). Upon dissipative balancing the excess energy is dissipated into heat - the energy is transferred to the needy cells and therefore is not lost) [6,7,8,9]. Redistribution is similar to the active balancing. But its DC-DC converters to be used, take more power and algorithms are a little more complicated. Dissipative (passive) EQU, used in the majority of these BMS [4,5] dissipating energy in all the cells until they reach the same level of voltage as in the weakest cell in the battery. Although the idea is quite simple and the price is low, it is obviously low energy efficiency. Disadvantages of passive balancing are obvious - is losing power at high currents passive balancing the heat generated can affect cells. At first glance, the active balancing is better because you do not lose power. In fact, the active balance has some drawbacks - there are more components with passive balance, higher cost, lower reliability, larger capacity, and others. In active BMS [2,8,9] is a distributed architecture where local (basic) units LM serve the battery module and send data to the central unit CM. Compared to the centralized structure, the distributed structure is flexible for different types of batteries and the number of the cell modules. It also significantly reduces the size and weight of the harness and wiring work [2].

However, since each of the local units in such systems measure only one of the battery module has a microcontroller and in each module, the cost of the whole system is quite high. Depending on the type and mode of administration can be selected in a simple or a more complex variation of the BMS. Major role in BMS is balancing the cells. Balancing algorithms (active or passive) may be based on the measurement of the following parameters:

Voltage ;

High voltage;

SOC history.

Based on the analysis we choose a combined approach - digitally measure the voltage of each cell and passive balancing end voltage under full state of charge SOC.

5. Characteristics of the chosen system for battery management

Developed by the authors hybrid management system (BMS) is tested and analyzed on a modular cell lithium-ion traction battery. This system monitor, control and balance the battery balancing battery, based on current accurate measurements of cell voltage and passive equalization parameters. In the work [7] the authors present a system for monitoring the battery status (MSB), which is part of the hybrid control system and battery management (BMS).

5.1. Modular approach for the measurement of parameters of the cells

Processing of data from the central module (CM) has been used scheme presented in Figure 1, where the measuring circuit shall be transferred to any voltage in the modules of common reference level in CM. This diagram shows a portion of a typical control system of a battery module, which uses one of these circuits for transfer in each of the local units (LM № 1 - № 4). In the displayed system for data collection using data from 4 cells in a module from the battery pack where the package contains 32 cells, which require measurements of tension in 8 local module (LM) [7]. This modular approach to measuring drastically reduces the amount of cabling that would otherwise be required for the connection between the CM and the cells of the battery.

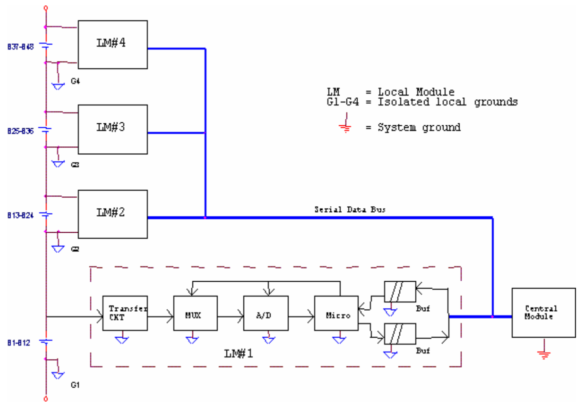


Figure 1. *Modular system for monitoring the Li-ion battery*

Transfer of compounds in each local module (LM) is used to make decisions on all 8 basic measurements to mass, ie, G1-G8. These voltages are multiplexed to power the A / D converter, are processed by a local microcontroller and transmitted to the CM isolated output signal via a serial data bus, such as CAN - 2.0b. This approach of establishing a chain transfer provides higher accuracy and has valuable advantages in comparison with previous methods, can be used for almost any number of battery modules. This is an important advantage, since each LM can measure large numbers of cells in order to reduce the total number of LM. This represents a large cost savings, because as shown in Figure 1, each LM typically comprises a multiplexer, A / D converter, a microcontroller, and two galvanically isolated serial bus buffer for data exchange. To provide the flexibility that BMS is designed to have the necessary features needed for Li-Ion batteries. Some of these include the following options:

1. Used multiplexing modular architecture of star topology, in order to avoid large wiring and each local

module can accommodate up to 4 cells. This provides a large reduction in the number of modules and loss [7].

2. Use new types of circuits for measuring the voltage and current to provide a greater precision. This includes automated calibration procedure that the correction factors are stored in flash memory.

3. Data for the battery can be stored in flash memory cm and a test disc in the computer.

4. All modules can be used to 2.0b serial communication for convenience and reliability.

5. When the battery is not in use, BMS enters into sleep mode at low power and measuring time in this mode. It also includes (activated) periodically to perform various functions and then goes back into Standby mode (freezes again).

Compared to previous systems, the new system provides dramatically reduce the cost, size and weight, all of which are critical in EV and HEV.

5.2. Principle of operation of the modular BMS

In Figure 2, an exemplary block diagram of a new modular system for Li-Ion battery. Below are four basic modules ECU / EQU, which consist of a LM and a passive or active EQU, a central ECU module and a DC / DC converter. Each base unit serves 4 cell battery. By changing some components, the system can be redesigned to be simpler (EQU can be passive or active), or serve more cells in the module, such as 12 or 24. Compared to previous systems, centralized, this modular structure reduces the cost of components considerably, especially when using passive EQU, which are suitable for normal charging of the battery in the EV bit / garage conditions. It also simplifies the installation and wiring work. In active EQU each LM is a combination of local ECU unit (microcontroller) and the local unit EQU, where the ECU controls the EQU. All LM, CM central unit ECU can communicate directly via the bus data 2.0b vehicle for data transfer. It is used both for internal and external communications, which simplifies the system because it provides

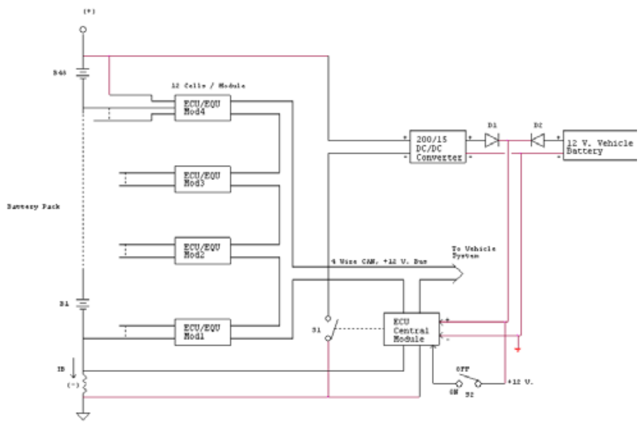


Figure 2. *Modular ECU / EQU system*

advantages - speed and reliabilityIf using passive EQU, the system is simplified further. When the system is off by S2, CM enters a low power "sleep" mode so that it retains its data in SRAM and measure and outside working hours. The system can be supplied or a 12V battery of the vehicle or the battery cell 32 through the DC / DC converter shown in Figure 2. Controlled switch S1 is closed when the main route of ECU loaded local units and the system will be powered by a DC / DC converter as a 12V (actually 9VDC_16VDC) battery remains below 15VDC. This mode is used so that the alignment can be done during parking without depletion (dilution) of a 12V battery. When the system is in standby mode during parking, S1 is open, DC / DC converter is disabled, SM plant is powered by battery 12V, with output of LM is excluded from the CPU. During the regime of standby, the plant consumes only about 8 ma current acceptable dilution 12V battery. DC / DC converter is switched off during a stop, because even at low load as 0.8mA., Its operating current is actually a few mA. This depletion would be excessive for a 32-cell battery during long periods of downtime. Local modules are connected with a central unit SM which ECU is the monitoring system, which can operate independently. Central unit ECU in CM includes responsibility for the following functions:

- Schedule power on / off local units;
- Measure the voltage of the synchronization between the local modules for data collection;
- Data collection, data processing and communication;
- Charge the battery current measurement;
- Determination of the status of the battery charge (SOC);
- Battery safety;
- Monitoring system during standby (standby);
- Management of equipment for maintenance of the battery.

Our version of BMS uses passive EQU each cell in each LM, which balance the weakest cell in each module bundled battery with a constant current until the voltage of all cells are equal. Operation of EQU is monitored by the ECU, which control various safety features, such as the temperature of each EQU in the local unit. The system is very simple and reliable, no need for additional DC-DC converters, and software, is under active EQU.

6. Experimental results

The prototype module is BMS-32 cells per pack Li-Ion battery (120V/100Ah), in order to verify its functionality and performance. There have been a series of tests between -20 º C and +40 º C with one of these modules connected to a 4 cell Li-Ion battery.

6.1. Voltage measurements

As described in [2], each local (reference) ECU uses measurement schemes voltage, using the following techniques:

1. Calibration factors stored in the flash memory in order to reduce errors due to initial tolerance.
2. Operational amplifiers, to reduce errors due to temperature fluctuations.
3. Sample / retention - schemes to reduce the problem of voltage distortion.

Results of testing for voltage measurement show the maximum error-9mV for cells with an average voltage of around 3.5V. This corresponds to an error of 0.26%, which is about half the size of the maximum estimated error of 0.51%.

6.2. Measurements of current (I) and the state of charge (Q)

Although they share certain elements in the same measuring circuit, the required accuracy for the I and Q measurements are quite different. Current I is mainly used for the protection and usually does not require a high degree of accuracy, ie error of 5% may be adequate. However, Q is obtained by integrating the measured current over long periods of time, and the error is cumulative. This means that if the measurement period is long enough, the problem will eventually become unacceptable, no matter what is the accuracy. This means that the SOC needs to be reset periodically with a precisely known value. In lithium-ion batteries for voltage stabilization may be used in coupling circuits to determine the SOC, when the battery is at rest. Regardless of the possible need for periodic reset, it is still important to strive for measurement methods that are as accurate as possible. Obviously, the higher the precision is accumulated charge Q, a longer period is necessary before the reset. The central ECU measured accumulated Q in the following manner. Resistive shunt is used to measure the current, voltage, frequency (V / F), as applied to the shunt voltage converter. Counter counts the number of pulses in V / F output for a given time interval. Q is thus obtained from very accurate integration of the measured current in the circuit to avoid many of the drift errors of analog integrators. As with the measurement of the voltage of the LM, a current measurement is pre-calibrated, the initial tolerance factors for the correction are stored on different parts of the entire measurement range. In order to evaluate the error over an extended period of time, to shunt voltage OCV is varied over a period of 36 minutes. Reset function of SOC is disabled during these tests to make sure that the counting of Coulomb will continue without interruption during the whole test period of 36 minutes.

6.3. Test alignment

In passive balancing every local EQU is set to dissipate excess energy in the cell when it reaches a specified end voltage. Cell temperature is monitored by a local ECU and when the temperature of the weak cell starts to increase (local EQU begins to dissipate heat from the weak cell) signals the CM problem, which is to decide when to turn off electricity to balance EQU, ie . when the voltage of the cell is aligned with the tension in the other cells. Equalizers begin balancing of the cell immediately after the full charge level is reached. The full charge is most often about 3.9V $LiFeYPO_4$ cells. The diagram in Figure 3. shows recharge 4 - cell module $LiFeYPO_4$ charged battery with the following configuration:

Cell 1 - no installed EQU;
Cell 2 - has installed EQU, (balance to 1.7A);
Cell 3 - installed EQU, (balancing to 3.4a);
Cell 4 - installed EQU, (balancing to 3.4A).

Shown in Figure 3 recharge current 5A. Section 1 (no equalizer) load goes above 4V level and voltage increases very fast, CM unloading a whole package. Cells 2, 3 and 4 are balanced with passive EQU and tension remains lower than 3.7V. On fig.3b e flashy charging current 10A. Section 1 (no EQU) pressure quickly goes over 4.2V level, the cell is recharged

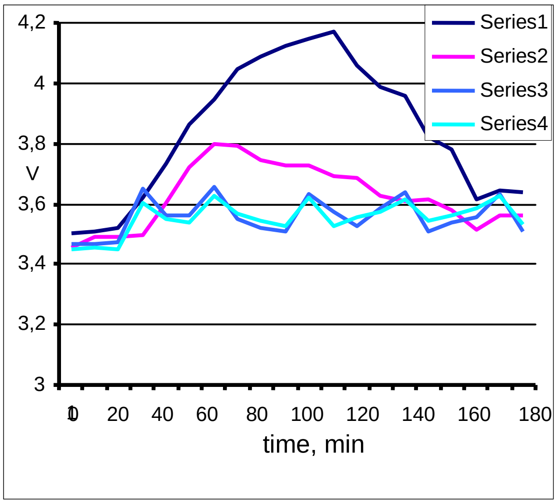
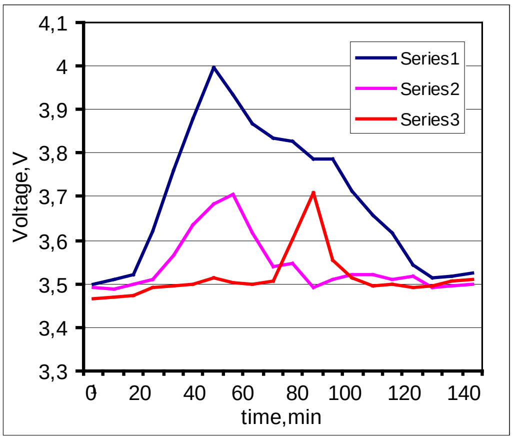


***Figure 3**. EQU function of passive cell balancing*

and there is danger of inflation, so the CM stops charging. Box 2 is balanced and voltage increases slowly to the border balancing. However balancing to 1.7A is not enough to 10A charge current. As a result, the voltage will rise above 3.8V, if not stopped by the EQU. Only box 3 and box 4 (a balance to 3.4 A) are balanced enough and the tension is kept lower than 3.7V. This experiment shows that EQU can balance $LiFeYPO_4$ cells easily, but for higher charging currents must be balanced with - high current balance in order to increase the overall balance of the current parameters. When selecting balancing power must take into account the heating of the cells at - balancing high current. For prismatic cell with a capacity of 100Ah



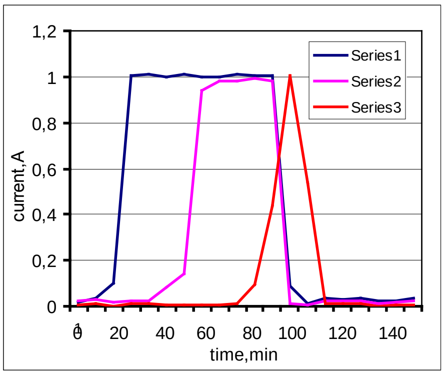


Figure 4. Operation of the BMS to balance

batterybalancing current should not be higher than 5A. The test of Figure 3 shows that EQU alone can balance the cells, but can not regulate current balance because you do not know SOC of each cell. Of FIG. 4 shows the results of testing of the modular BMS balancing of the same cells with consideration of SOC levels. SOC exact values of each of these cells e: SOC1 = -20,7%, SOC2 = -16,1%, and? SOC3 = -15,1%. The system is turned on and V = Vn measured against time (n = number of the cell.) For each of the three cells having EQU.

Cell № 1 which has the highest voltage V is again balanced in less than 0,5 V within 60 minutes. This block continues to be aligned to 130 minutes. Cell № 2 then is equalized for about 75 min and finally the cell 3 is equilibrated for about 30 minutes to complete the process. All cells 3 are aligned within 140 minutes. It should be noted that since only the currents are measured every 15 min, the graph of Figure 4b are not quite accurate e. The time for increasing and decreasing the current really has nastapr of less than 1ms, for a 15 minute interval as a graph. E first point at t = 0 sec.

The new modular system, LM with ECU / EQU modules are mounted on the battery so that the sensor wires are very short and can be shared. Their weight is negligible, since the length is very short. The cable between LM and CM contains only four # 22 AWG cable.

6. Conclusion

• Based on the analysis of the conditions and technical parameters of existing systems for battery management has developed a new technology for BMS.

• Developed and tested a modular system for battery management. This BMS provides important advantages in these areas: voltage measurement accumulated charge for measuring and leveling.

• Measurement of the voltage is achieved with a very accurate, which provides up to 4 measurements of the module in order to reduce costs.

• Measuring scheme using an accurate charging V / F converter in conjunction with a meter to integrate the current waveform. This extends the time before you need to restart the measurement.

• The alignment is performed using relatively low power routing, which increases the charging module for low voltage, instead of the more commonly used method of implementation of modules with higher voltages. All functions have been tested and verified to pack Li-Ion battery with 32. cells.

• Surface mount technology is used throughout to reduce the size, weight and cost. The weight and volume of the modular system are 70% and 87% less than a common centralized systems.

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