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Research on balancing BMS systems in a climatic chamber

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Abstract:

Assumptions for testing the selected lithium cells in the climatic chamber are presented. Two different active balancing methods and one passive will be used. Three batteries consisting of eight cells each will be build for this purpose. The tests were aimed at determining the impact of cells temperature on their balancing process. They have many advantages over the traditional lead-acid batteries. The most important advantages include fast charging, high energy density and power as well as a wider range of operating temperatures. However, they require the use of battery surveillance and management systems (BMS) to increase work safety. One of the most important functions of such a system is the method of balancing, i.e. charge equalization of each cell.

Streszczenie:

W artykule przedstawiono założenia do badań wybranych metod balansowania ogniw litowych w komorze klimatycznej. Zostały zastosowane dwie różne aktywne metody balansowania oraz jedna pasywna. W tym celu zbudowane zostały trzy akumulatory składające się z ośmiu ogniw każdy. Badania mają na celu sprawdzenie, jaki wpływ na balansowanie ogniw ma temperatura pracy ogniw litowych. Ogniwa litowe posiadają wiele zalet w porównaniu z tradycyjnymi akumulatorami kwasowo-ołowiowymi. Do najważniejszych zalet można zaliczyć możliwość szybkiego ładowania, wysoką gęstość energetyczną i moc oraz szerszy zakres temperatur pracy. Jednak wymagają one zastosowania systemów nadzorujących i zarządzających baterią akumulatorów (BMS Battery Management System) w celu zwiększenia bezpieczeństwa pracy. Jedną z ważniejszych funkcji BMS jest zastosowana metoda balansowania, czyli wyrównywania poziomu naładowania poszczególnych ogniw.

1. Introduction

Batteries made of lithium cells appeared in a commercial application in the early 90's and quickly began to spread. Today, various lithium batteries are available, and their popularity is growing rapidly. They are widely used in mobile phones, tablets, laptops, cameras, power tools, in electric and hybrid cars, in aviation, as well as in the mining industry, where they start to replace the acid-lead batteries used so far.

Lithium batteries offer the highest energy density from all the batteries available on the market. However, they require quite a special attention because both overloading and over-discharge can lead to permanent damage. In order to eliminate such cases, it is necessary to use appropriate safeguards, mainly electronic ones, as well as a special casing protecting them against overheating, moisture, vibrations and mechanical damages.

Effective protection of cells can be obtained by using special electronic circuits referred to as BMS (Battery Management System), which are used for a specific battery solution adapted to the number, type and method of connecting cells [1, 2, 3, 4].

The BMS system has several functions, such as: measuring the cell voltage, current and temperature, cell charge level, cell protection, temperature management, charging / discharging control, data acquisition, communication with internal and external modules, monitoring and storage of previous data, and voltage equalization on battery cells.

The discrepancies on the cells in the battery system are very important for the battery life, because without the equalizing system, the voltage on each cell may, after some time, appeared to be different. The capacity of the entire pack can also quickly decrease during its operation, what can be a reason of loss in the battery system ability for further operation.

2. Balancing Cells

Balancing cells methods can be passive or active. Balancing of battery cells consists in equalizing the charge level of all cells, which is realized by the system specially designed for this purpose. This is necessary because each cell, even this supplied by the same manufacturer, can differ in their levels of maximum discharging, capacity and internal resistance. These differences can increase during operation. Operation of cells in different temperatures may be an additional unfavourable factor [5, 6, 7].

This results in a final different level of charge, which in turn affects the total battery capacity (some cells in an imbalanced battery can discharge or charge faster than others). Balancing the cells is recommended for the batteries consisting of three cells, and in the cases of a larger number, it becomes necessary [3].

Effective battery pack diagnostics is required to be a reliable and stable sources of electricity for as long time as possible, having high energy efficiency and a high level of safety.

The cell balancing methods can be divided into three main groups (Figure 1):

- battery selection (setting the battery pack by selecting the cells of similar properties),
- passive methods (no active control is used to balance),
- active methods (external circuit with active control is used to balance).

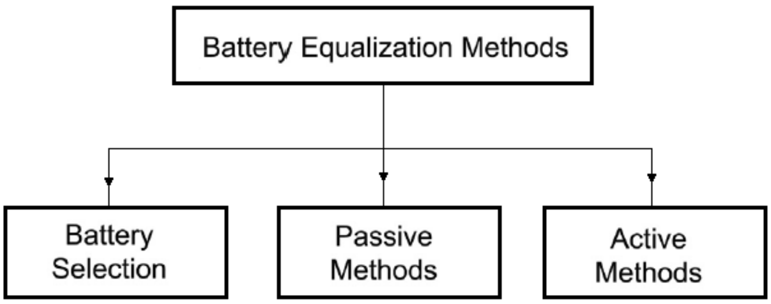

Fig. 1. Classification of the battery equalization methods [3]

Battery Cells Balancing by the Cell Selection Method

The battery pack consists of the selected cells. They are selected in terms of uniformity of electrochemical properties. This type of cell selection does not require cell balancing, because the voltage and current differences are neglectable [8, 9].

This method is not sufficient to keep the battery cells connected in series in balance throughout their lifetime. Significant differences associated with their self-discharge and different levels of charge associated with aging of the cells may occur over time. This method can only be used for the selected cells [10].

Passive Cell Balancing

Passive balancing consists in dissipation of excessive energy to resistors. In this case, the voltage of each cell is monitored in the microcontroller through an analogue-to-digital converter, on whose input terminal the cells are switched on through the multiplexer. If the voltage of one of the cells significantly exceeds the voltage of the other cells, it is closed by a switch. As a result the cell is discharged through a part of the passive balancing circuit – a resistor, connected in parallel with each cell and lasts until the voltage of the overcharged cell equals the voltage of the other cells. Then charging of the pack continues. At the same time the voltage of all other cells is monitored [8, 11, 12].

However, the passive balancing has some disadvantages. One of them is low efficiency, resulting from the fact, that the excess energy accumulated in unbalanced cells is lost in the resistor and converted into heat. In addition, the total capacity of the battery pack is limited by the need to adjust the charge level of the cells to the capacity of the "weakest" cells [13, 14].

Therefore, passive balancing can only be realized during the cell charging process. However, in this way it is impossible to prevent the imbalance of cells that occurs during their use and which is usually a consequence of self-discharge [15, 16].

However, overcharge equalization is only effective for a small number of cells connected in series, because the difficulty of equalization increases exponentially relative to the number of cells connected in the series. In general, these methods are cost-effective solutions for low-voltage lead-acid batteries and those based on nickel compounds.

Active Cell Balancing

Active cell balancing is am alternative methods to the passive method. The main idea is to use an external system designed for active energy transfer between cells. The method of active cell balancing can be used in most innovative lithium cells, due to the temperature of this type of cells, which must be strictly controlled for safe operation [17, 18, 19, 20, 21].

There are many methods of active cell balancing and the methods are divided in different ways. Due to the flow of energy, the methods are grouped into five basic subcategories (Figure 2): cell bypass, cell to cell, cell to battery pack, pack to cell and cell(s) to pack and to cell(s) [3].

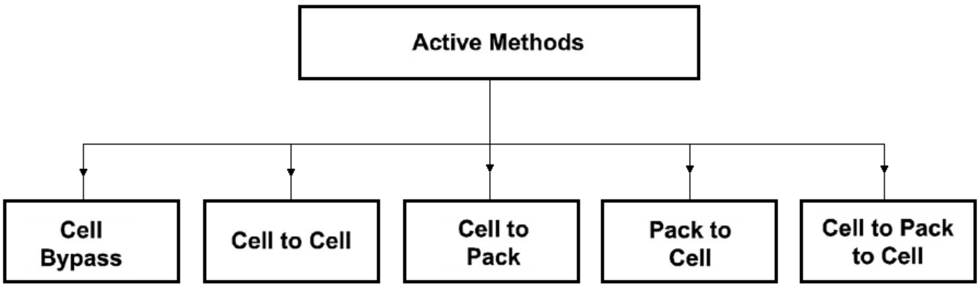

Fig. 2. Classification of the different active balancing methods [3]

3. Lithium cells

The purchased Headway LFP38120(S) lithium cells (Fig.3) were used to build three battery packs consisting of eight cells each (Fig. 4).

Fig. 3. Headway LFP38120(S) 10000 mAh cell

Technical data:
- voltage: 3.2 V
- capacity: 10 Ah
- internal resistance: < 6 mOhm
- charging voltage: 3.65 V±0.05 V
- energy density: 105 Wh/kg
- technology: lithium-iron-phosphate ($LiFePO_4$)
- maximum discharge voltage: 2.5 V-2.0 V

standard charging current: 0.5 C (5 A)
standard charging time: 2 h
maximum direct charging current: 2 C (20 A)
standard discharging current: 1 C (10 A)
maximum direct discharging current: 3C (30 A)
impulse discharging current: 10 C (100 A)
Range of operational temperatures:
– charging: 0 ÷ 45ºC
– discharging: -20 ÷ 65ºC
life: over 2000 cycles (80% of capacity when loading with 1C current).

Fig. 4. Battery pack made of eight lithium cells

4. BMS systems used for testing

Three BMS systems were used for testing. Two active ones were designed and manufacture in KOMAG, the third passive one BMS ORION was purchased.

BMS system with the passive balancing

The system works by dissipating the excess energy into heat using resistors (Fig. 5). In this case, the voltage of each cell is monitored in the microcontroller through an analogue-to-digital converter, the input of which, through a multiplexer, is connected to individual cells. If the voltage of one of the cells significantly exceeds the voltage of the others, it is closed by a proper switch. This results in the discharge of the cell through the passive balancing circuit component - a resistor, connected in parallel with each cell and lasts until the voltage of the overcharged cell equals the voltage of the other cells. Then loading of the packet continues. At the same time, the voltage of all other cells are monitored.

Fig. 5. System BMS ORION

Technical data:

- Number of cells – 16
- Maximum current – 350 mA
- Maximum switch on voltage – 3.8 V
- Minimum switch off voltage – 2.0 V

BMS system with active balancing by the cell to battery method

The cell to battery method consists in transferring the energy from the mostly charged cell to the entire battery.

BMS system consists of the following:

- BMS-S modules (Fig. 6) – assigned to each cell, used to measure its parameters and realization of the balancing process, i.e. energy transfer to other cells,

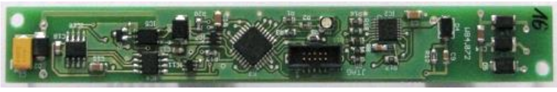

Fig. 6. BMS-S module

- Assembly board (Fig. 7) – installed on each pack, the board integrating the BMS-S modules, have no programable logics, have the circuits associated with communication and energy exchange among the packs,

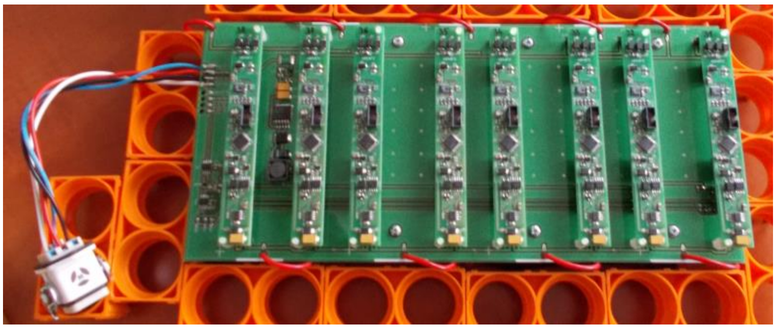

Fig. 7. BMS-S modules installed on the assembly board

- BMS-M module (Fig. 8) – master control system, used to control operation of all modules making the BMS system as well as for supervising the battery operation.

Fig. 8. BMS-M module

Data between modules is exchanged using the RS485 series interface and the MODBUS RTU protocol.

The BMS-M master module is equipped with a CAN communication bus. Measurement data will be read and recorded by the CAN Studio program.

Configuration active balancing by the cell to battery method

Active balancing realized by the BMS system, balances the charges on each battery cell. Modules built on cell packs are used to transfer charges (Fig. 9).

Fig. 9. BMS installed on the cells pack

Energy is collected from single, overcharged cells, and then transferred to be used in the case of battery operation in discharge mode, or returned to packs, in the case of battery operation in charging mode.

BMS system with active balancing by the battery to cell method

The battery to cell method consists in transferring the energy from the mostly charged cell to the entire battery.

BMS system consists of the following:

- measuring and controlling module (Fig. 10) – controlling system used to measure cells voltage and for control of BMS operation as well as for supervision over the battery operation,

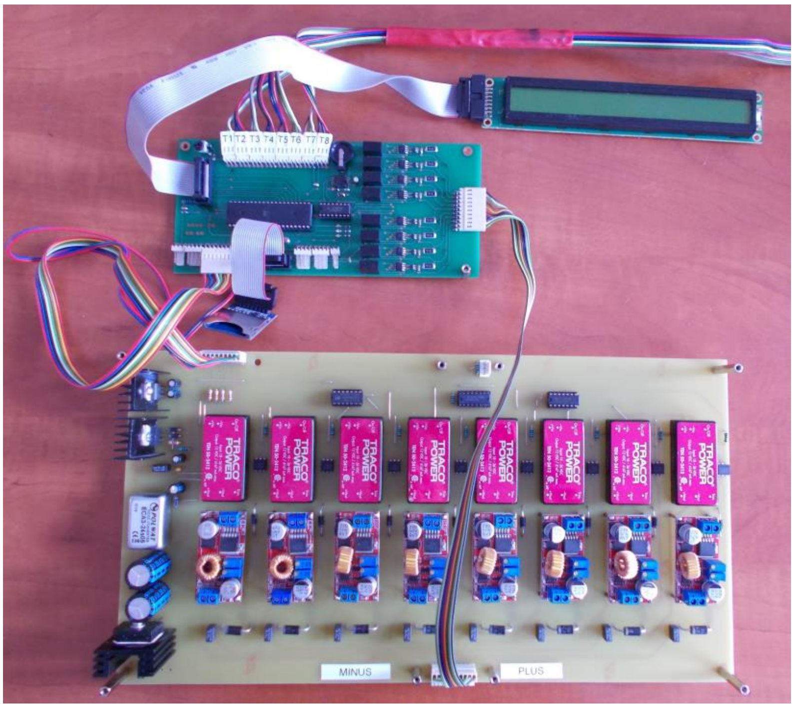

Fig. 10. Measurement and control module

- balancing system module (Fig. 10) - assigned to each cell, used to measure its parameters and realization of the balancing process, i.e. energy transfer to other cells.

The measurement data are read out and recorded on SD card.

Configuration active balancing by the battery to cell method

The active balancing method uses a galvanically separated converter as the cell charging system. Its primary winding is connected to the pack of cells, and the secondary winding is connected to the cell through a rectifier and relays. The energy transferred to the cell has the form of short pulses selected by the electronic controller.

5. Test stand

Test stand with a climatic chamber was built at KOMAG for testing the BMS systems and lithium cell batteries. It is shown in Fig. 11 and Fig. 12.

Fig. 11. Arrangement of battery packs in the climatic chamber

Battery pack 1 connected to the BMS with passive balancing.
Battery pack 2 connected to the BMS with active balancing using the cell-to-battery method.
Battery pack 3 connected to the BMS with active balancing using the battery-to-cell method.

Fig. 12. Arrangement of battery packs in the climatic chamber

The stand consists of the following components:
- climatic chamber,
- battery packs made of Headway LFP38120 (S) LiFePO4 10Ah lithium cells,
- *DT8873-24* ***VOLTpoint*** measuring system,
- temperature measuring system,
- laboratory power supply units,
- computer with a special software.

6. Scope of tests

The scope of tests included the measurement of the surface temperature of the lithium cell during discharge and balancing, and the cell voltage at the same load. During cells discharging and balancing, the maximum and minimum voltage was within the limits provided by the manufacturer.

The tests consisted in discharging a single cell to the minimum limit specified by the manufacturer and balancing all cells in the batteries.

The tests were performed in a climatic chamber for the temperature of + 5°C and humidity of 75%. During the tests, cell voltages and temperature distribution on the cells enclosure in the batteries were recorded.

AD22100 temperature sensor

The AD22100 sensors from Analog Devices were used to measure temperature. Temperature sensors were installed on the cell's enclosure in the middle of its length.

Technical data:

Temperature sensor type	digital
Temperature measuring range	-50...150°C
Accuracy of temperature measurement	±0.5°C
Sensor characteristics	temperature coefficient of 22.5 mV/°C

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Configuration of the BMS systems

Technical parameters were configured in the same way to compare the operation of two BMS active balancing methods. In both systems, balancing begins when a cell voltage lower than 3.05 V is detected, while balancing break occurs when the voltage on all cells is lower than 2.55 V or when the voltage on any of the cells is lower than 2.5 V or greater than 3.65 V. The balancing current is set at 2 A.

In the case of the purchased BMS system with passive balancing, the balancing current was set by the manufacturer to 350 mA, while the technical parameters were set using the software. In a result of the configuration, the balancing of the cells was set and it activates when a voltage above 3.2 V is detected on the cell and is turned off when the voltage on any cell is lower than 2.5 V or greater than 3.65 V. The balancing process is activated when the cell voltage ranges between 3.2 V and 3.6 V.

7. Test results

The presented diagram show that depending on the type of BMS system, the service life of the lithium battery changes. The most advantageous system seems to be the BMS system with active balancing by the battery-to-cell method, because it maintained the voltage above the minimum for the longest time on the discharged cell (Fig. 13). This situation is beneficial for the user, as it extends the battery life without having to stop operation while charging.

In the second battery with a connected BMS system with active cell-to-battery balancing, the voltage on the discharged cell also remained long above the minimum compared to a battery with a passive BMS system, but shorter than with a BMS system with active battery-to-cell balancing. On the other hand, in a battery with a connected BMS system with passive balancing, the loaded cell was discharged the fastest, which causes shorter battery life and more frequent breaks due to charging.

During the test, temperatures were measured on all cells of the tested batteries. The temperature difference between the beginning and the end of the test did not exceed 2°C and amounted to 4°C to 6°C, what means that the load to the cells did not have a large impact on the warming-up of the cells. Such a situation will not be dangerous if the battery consists of hundreds of cells and their cooling is limited and unequal. Then the risk of exceeding the permissible temperature of the cells inside the package will be unlikely.

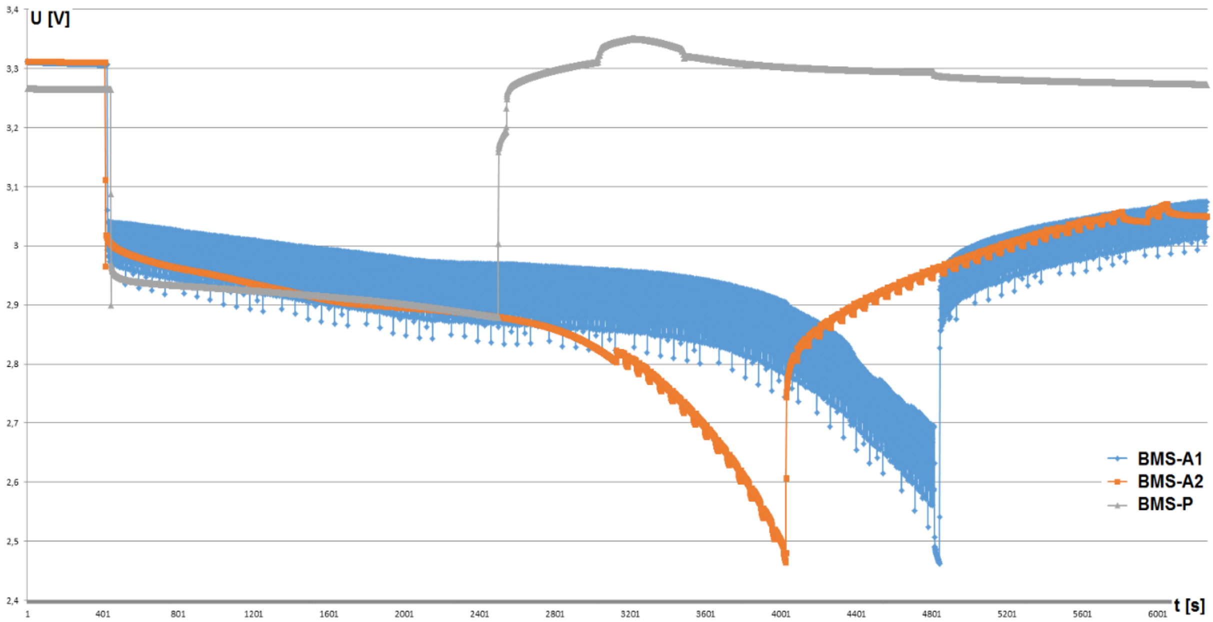

Fig. 13. Diagram of the voltage changes on a loaded cell for all tested BMS systems
BMS-A1 – BMS with active balancing, the battery-to-cell method
BMS-A2 – BMS with active balancing, the cell-to-battery method
BMS-P – BMS with passive balancing

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8. Conclusions

The test shows that the battery pack containing the LiFePO4 cells should be controlled by a BMS system with active balancing to fully use up all the stored energy. Various factors can contribute to faster wear of the lithium cell. This is mainly due to the gradual change in the properties of the active materials.

There are variety of cell balancing systems that can work with batteries used in the mining equipment and machines. The selection of such a system should be customised to the specific application, regarding the maximum and minimum voltage, operating temperature and the capacity of the cell used, given by the manufacturer. Additionally, when using active balancing, the charging current of the cells should be selected depending on the cell's capacity. However, in the case of using passive balancing, depending on the cell's capacity and the charging current, the appropriate power of a shunt resistor connected in parallel with each cell should be selected, which shunts the charged cell, losing the excess energy to heat.

Passive cell balancing methods are the cheapest but also the least effective. They are used in batteries with a small number of cells connected in series because the difficulty of equalization increases with the number of cells in a row. The main disadvantage is the low efficiency, due to the fact that the excess energy accumulated in unbalanced cells is lost to heat in the resistor.

However, the methods of active balancing of cells can be used in majority of state-of-the-art cells from the lithium group. This method allows energy to be transferred between the cells while charging, discharging or not used. This is its big advantage compared to the passive balancing method, because some of the energy losses occur mainly in the systems that convert and transfer some of the energy to the remaining battery cells.

Comparing both passive and active methods, it should be stated that the methods of active cell balancing are more efficient.

As it was the first initial test, it was decided that in order to draw conclusions from the operation of BMS systems, further tests should be performed for the remaining temperatures. After obtaining all the test results, it will be possible to compare the characteristics and draw conclusions as to the impact of the temperature of the working environment of lithium cells on the effect of cell balancing.

Preparations are currently underway for further testing of lithium cells in a climate chamber. It is planned to perform the following series of comparative tests on cells at different temperatures, i.e. +5°C, +20°C, +45°C, +60°C:

- single cell discharge and balancing,
- two cells discharge and balancing.

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