Tests of BMS Battery Management System with active and passive system of balancing the battery capacity

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Abstract. The tests of two BMS Battery management systems, equipped with active and passive systems of balancing the battery capacity, realized within the framework of the HYDKOM 75 project, are discussed in the article. These tests were performed on the lithium-ferric-phosphate (LiFePO₄) battery assembly for the mining mobile machine of BH 3000 B HYDKOM 75 type. The object of tests included two Battery Management Systems (BMS). The first one was a commercially available system most often used in the automobile industry, however the second one was the author’s BMS-Battery Management System developed at the KOMAG Institute of Mining Technology with active system of balancing the battery capacity. The tests were conducted both during a battery charging process as well as during discharging the LiFePO₄ battery for different values of the load current.

1. Introduction

Tests of two BMS-Battery Management Systems were conducted within the framework of the HYDKOM 75 project [1]. The first system was commercially available (Orion BMS Original) with passive system of balancing the battery capacity, most often used in the automobile industry. However, the second one was the author’s BMS management system developed at the KOMAG Institute of Mining Technology with active system of balancing the battery capacity. The tests were conducted on the assembly of lithium-ferric-phosphonate (LiFePO₄) batteries for the mining mobile machine of BH3000B HYDKOM 75 type. The ideas of BMS systems functioning and their realization of battery balancing processes are discussed in the article. The object of tests is characterized and the tests of two BMS -Battery Management Systems, conducted at the KOMAG Institute, are described.

2. Idea of BMS system functioning

Monitoring and control processes of energy storage in battery assemblies enable their functioning as long as possible, being reliable and stable sources of electric energy. They are characterized by a high efficiency and high level of safety. The diagnostics is realized with use of the BMS-Battery Management Systems. The BMS system, operating correctly prevents any damage to battery, e.g. in the result of its overcharging, excessive discharging or exceeding its temperature limit. The BMS systems also perform a function of a meter of a battery charging level. Besides, they can check a conformity of its characteristics with a receiver requirements and optimize the battery charging process to increase its efficiency. A need of using BMS systems results from an application of new generation batteries, in particular lithium ones, very sensitive to overcharge and excessive discharge.
BMS systems enable to protect assemblies of batteries against inequal charge of its individual batteries as well as against overcharge and excessive discharge. In the case of using a battery assembly composed of several batteries, it is indispensable to equalize their capacities. Equalizing of capacities of batteries consists in equalizing the charge level of all the batteries, which is realized by means of especially designed circuit. Two solutions can be distinguished in this scope: a configuration with a passive or active balance.

2.1. Passive method of battery capacity balancing

An example of the battery capacity passive balancing is shown in Figure 1.

![Figure 1. Example of balancing battery assembly capacities [2].](image)

Values of voltages in individual batteries are monitored in the microcontroller by means of the A/C converter, on whose input individual batteries are switched on via a multiplexer. If a voltage of any of the batteries exceeds voltages of the other ones significantly, an appropriate key S is closed. It causes a discharge of the battery by an element of the passive balancing circuit (by a resistor), connected in parallel to each battery and it lasts till the voltage of the overcharged battery is equal to the voltages of the other batteries. Then charging of the packet is continued. Simultaneously, the voltages of the other batteries are controlled all the time.

However, passive balancing of batteries has faults. One of them is a small efficiency resulting from the fact that the energy surplus, stored in the unbalanced batteries, is lost for heat energy in the resistor.

Besides, the total capacity of the battery assembly is limited due to a need of adapting the battery assembly charge level to the capacity of the ‘weakest’ battery.

2.2. Active method of battery capacity balancing

An alternative solution to passive method of battery capacity balancing is the active method. An example of active balancing of the battery assembly capacities is shown in Figure 2.
The active method consists in a conversion of the overcharge from the overcharged battery to the undercharged one (or several). Transistor keys are usually used for this purpose, similarly to the passive method, but instead of resistors an induction coil, being the transformer secondary winding, is connected to the battery.

A reduction of voltage in an overcharged battery consists in its instantaneous connection to the respectful secondary winding of the balancing system, which results in an induction of voltage in the primary winding. The battery key is then opened, but the key of another undercharged battery (or several batteries) is locked. Due to that the energy from the transformer primary winding is transferred to the secondary winding i.e. to the battery.

3. Object of tests
Two BMS systems, were objects of tests. The first one was a commercially available system (Orion BMS Original) with the passive system of battery capacity balancing. However, the second one was the author’s BMS – Battery Management System with the active battery capacity balancing system, developed at the KOMAG Institute of Mining Technology.

3.1. Orion BMS Original system with passive system of battery capacity balancing
The Orion BMS Original system with the passive system of battery capacity balancing (Figure 3) is commercially available and commonly used in the automobile industry.
The Orion BMS Original is characterized by:
- a possibility of measuring up to 180 batteries connected in series,
- a high electromagnetic noise immunity,
- a possibility of calculating the charge degree (SOC),
- professional interlocking connectors of automobile class,
- a possibility of calculating the discharging current limit (DCL) and the charging current limit (CCL),
- a possibility of measuring voltage of a single battery between 0.5 and 5.0V,
- double interfaces CANBUS 2.0B (fully programmable),
- a possibility of using ODB2 diagnostic protocol.

3.2. BMS – Battery Management System with active battery capacity balancing

The BMS – Battery Management System with the active battery capacity balancing (Figure 4) consists of:
- BMS-S modules, assigned to each battery, are used for measurements of parameters and for a physical realization of the balancing process, i.e. transferring the energy to the other batteries,
- Mounting plates - the plates integrating the BMS-S modules, containing the circuits connected with communication and energy exchange among packets, installed on each packet, do not have any programmable logic,
- BMS-M module – superordinated control system is used for a control of all the constituent modules of the BMS system for a management of the battery operational parameters.

A part of the BMS system, designed for an installation in a single packet, consisting of 16 Lithium (LiFePO$_4$) batteries of 100Ah capacity each.

![Figure 4. BMS management system with active battery capacity balancing [3] developed at the KOMAG Institute: 1) BMS-S modules, 2) mounting plate, 3) BMS-M module.](image)

The data, among all the modules of the BMS system, are exchanged by means the RS485 interface in series and the MODBUS RTU protocol. The BMS – M superordinated module is equipped with the CAN communication bus.

4. Tests of BMS systems

The tests of the BMS systems, described above, were conducted on the lithium – ferric – phosphate (LiFePO$_4$) battery assembly developed and constructed for the mining mobile machine of BH 3000B
HYDKOM 75 type. The battery consisted of 224 cells connected in series and divided into 14 battery cassettes, 16 cells in each cassette (Figure 5).

Figure 5. Single battery cassette containing 16 lithium – ferric – phosphate cells [3].

Basic technical parameters of the battery, operating together within BMS systems under testing, are presented in Table 1.

Table 1. Basic technical parameters of cell battery.

| Parameter                                | Value   |
|------------------------------------------|---------|
| Number of cells connected in series      | 224 pcs.|
| Rated voltage of single cell             | 3.2V    |
| Maximal voltage of single cell           | 3.65V   |
| Minimal voltage of single cell           | 2.65V   |
| Battery rated voltage                    | 716.8V  |
| Battery maximal voltage                  | 817.6V  |
| Battery minimal voltage                  | 593.6V  |
| Rated capacity                           | 100Ah   |
| Charging current                         | 30A     |
| Maximal discharging current              | 100A    |

4.1. Tests of Orion BMS Original management system with passive balancing system

The tests of the BMS system with the passive balancing system were conducted during charging and discharging of the battery assembly. The voltages on each battery cell were monitored during the tests. Due to a big number of the battery cells (224 pcs.) two BMS equipment were used in the system. The communication between them was realized by means of the CAN bus.

In Figures 6 and 7 exemplary screen monitoring balancing of the battery cells (for BMS1 – Master and BMS2 – Slave) are presented. The fields marked in red signal balancing of individual cells.

Figure 6. Screen during the monitoring of balancing the BMS1 – Master battery cells [3].
Figure 7. Screen during the monitoring of balancing the BMS2 - Slave battery cells [3].

Charging of the battery assembly was conducted at the battery charging rate $I_{charge} = 30$A DC. During charging, the voltages on all the cells of the battery assembly were measured. A dozen or so charging cycles were performed. During the tests, it was observed that while charging the first cell, counting from the negative end of the battery cassette, it was different, as regards its parameters, from the other cells in a given cassette, i.e. the voltage was higher than in the case of the other cells in the same cassette.

However, discharging of the battery was performed for different values of the load current intensity ($0.5I_n$, $1.0I_n$, $1.1I_n$). During discharging (similarly to charging), the voltage on the same cell was significantly lower than in the case of the other cells in the same cassette. All the other cells in a given cassette kept similar voltage parameters. Exemplary voltages during charging and discharging of individual cells for one selected cassette of the cell battery are presented in Figures 8 and 9.

Each of the conducted full charging and discharging cycles was performed without any disturbances. No exceeding of equipment permissible operational parameters was recorded. The BMS management system under testing operated correctly.

Figure 8. Voltages on the KS5 cassette cells during charging [3].
Figure 9. Voltages on the KS6 cassette cells during discharging [3].

In the case of the conducted tests the charging ended when a single cell achieved the maximal voltage, i.e. 3.65V. However, the discharging process ended when a single cell achieved the minimal voltage, i.e. 2.65V. The test results confirmed an efficiency of capacity balancing with the charging current of 200mA and an activation of protections, when the extreme values of voltages and temperatures in the cell battery were exceeded.

4.2. Tests of BMS – Battery Management System with active balancing system
In the next stage some tests of the author’s BMS – Battery Management System with the active capacity balancing system were conducted. The tests consisted of two parts. First a calibration of the system at the laboratory stand was performed. Then the BMS system modules were installed on four cell packets (Figure 10). An installation of the BMS system only on the four cassettes was due to the costs of a big number of electronic components indispensable for a construction of the BMS management system.

Figure 10. Four battery cassettes containing 16 LiFePO₄ cells with BMS management system and active balancing system of cells [3].
During the tests an operation of the balancing circuits at full charging and discharging cycles was checked. The tests of the BMS system enabled to adapt the procedure of active balancing in relation to the number and type of cells. The conducted tests showed that modules of the BMS system, installed on the cells, ensure correct balancing of their charges. The tests enabled an empirical determination of the voltage limits on individual cells, at which a realization of balancing (equalization of charges) was most efficient. It can be concluded from the tests that the voltages in individual cells are within the range from 3.23V to 3.30V. The tests confirmed the efficiency of capacity balancing within the charging current 2A which is 10 times higher than in the case of the BMS system with the passive capacity balancing system.

5. Conclusions
The tests of the BMS – Battery Management Systems conducted within the framework of the HYDCOM 75 project are discussed in the article. These tests were realized on the lithium – ferric – phosphate (LiFePO4) cell battery assembly developed and constructed for the mining machine of BH 3000B HYDCOM 75 type. Two cell battery management system (BMS), equipped with the active and passive cell capacity balancing systems, were subject to tests. The commercially available (Orion BMS Original) system, dedicated mainly for use in electric cars, was tested first. The tests confirmed an efficiency of capacity balancing with charging current of 200mA and an activation of the protections when exceeding the limit values of voltages and temperatures on the battery of cells. The battery management system (BMS) with the active balancing system, developed at the KOMAG Institute of Mining Technology, was subject to tests as the second one. This system consisted of BMS-S modules installed on the basic plates, enabling a connection to the packet cells and of the BMS-M management module. The management system was developed for four battery cassettes (64 pcs. of single cells). The tests confirmed the efficiency of cells’ balancing with charging current of 2A.
From a comparison of both BMS systems it can be concluded that from the point of view of the active cells balancing, where balancing was realized with the current of 10 – times higher intensity, the author’s solution is more advantageous. Besides, it should be highlighted that while using the active capacity balancing, the energy stored in the battery is not lost for heat as it occurs in the systems with the passive capacity, balancing system. However, due to an economic aspect of the system construction for the whole cells’ battery, it was decided that an implementation of this solution, during the commercialization stage of the project results, will be realized upon a future user’s individual request.

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