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VERIFICATION OF $LiFePO_4$ BATTERY MATHEMATIC MODEL

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Abstract

Article presents verification of $LiFePO_4$ battery simulation model. Verification of battery model was made to assure real parameters of battery cells used for simulation. Simulation model of battery and test stand, similar to the stand used for test on a real battery, was designed in AMESim software. Data of the battery and single cell of battery characteristics were verified to assure true parameters for further tests of power transmission system of the vehicle. For verification theoretical model of the battery, real tests of battery discharging were performed in laboratory. Test stand used for battery discharging was build. Test stand was equipped in water resistor enable to set up various loads of battery. Electrical parameters of battery and battery cell were collected by voltage probes and current clamps and stored in database. Test was performed in similar condition, each time starting with fully loaded battery. Tests ends when battery management system shut down battery main switch. Tests conditions, virtual and real, were performed during similar battery load. Comparing data from unloading tests in laboratory enable to verify data of battery and battery cells designed in AMESim software. Such verification provide reliable model of the used battery. Model of the battery can be used in further simulation test of vehicle, where battery is installed.

Keywords: *battery, $LiFePO_4$, test stand, simulation model*

1. Introduction

Battery of modern vehicles, both electric and hybrid, are most rigorous assess element of vehicle power transmission system. It is mainly because of battery, features depend vehicle's parameters: its range, battery capacity and voltage of the battery to provide vehicle use according to its design.

Unproper selection of battery in designed vehicle could have big influence on vehicle's range and it's overmotoring, in respect to vehicle's application, could affect higher price of vehicle, which is mostly depend on battery type and capacity and also construction of whole vehicle, because as studies show, according to [3, 4], increasing mass of battery by 100 kg result increasing mass of other elements of the vehicle such as brakes, suspension, frame, etc., c.a. 58 kg.

During use of electric and hybrid vehicles, significant problem is to determine vehicles traction characteristics from the point of view of energy or fuel use, range of vehicles or dynamic properties. It is a complex problem and requires considering many factors, occurring beyond exploitation phase of vehicle.

Article presents investigation of lithium-polymer battery ($LiFePO_4$) on a test stand equipped with resistor for battery loading. Battery came from hybrid power transmission of small-unmanned vehicle, which was widely presented in [5-7]. Nominal voltage of battery was 48 VDC. Battery consists of twelve cells of 70 Ah capacity [2].

Data acquired during measurements helps to create simulation model of the test stand, designed in AMESim software, and model of battery and single cell of battery. This enables to verify model with data from the test stand. Used software enable to design and evaluation of designed model and correcting without need of create expensive prototypes.

Tests were performed on a stand equipped in water resistor. The role of resistor was to discharge of battery and comparison of collected data with simulation model. Those tests enable to receive a very precise model of battery and its behaviour during different load conditions. Verified model can be used for simulation experiments of whole power transmission system of the vehicle.

2. Test stand

Tests of the electrochemical battery consist on discharging fully loaded battery and measuring its parameters, (voltage, current and temperature) in function of time. Performed tests enable to determine parameters of battery – operation time vs. discharging current, comparison of battery with its simulation model. This model enables further tests of hybrid power transmission of vehicle.

Scheme of the test stand is shown on Fig. 1. It can be seen water resistor (1), voltage and current probes (2) and the battery (3). Number 4 presents PC computer with connected acquisition cards.

Tested battery was equipped with three voltage probes:

1) voltage probe on the battery output with scaling,
2) voltage probe on single battery cell with scaling,
3) voltage probe on aa singe battery cell without scaling.

Voltage probes with scaling were put for adjusting measured voltage with voltage meter range.

On the output of the battery, two current probes were placed for current measurement. Test stand was modified according to test needs. The higher current was used, the more panels of water resistor were used.

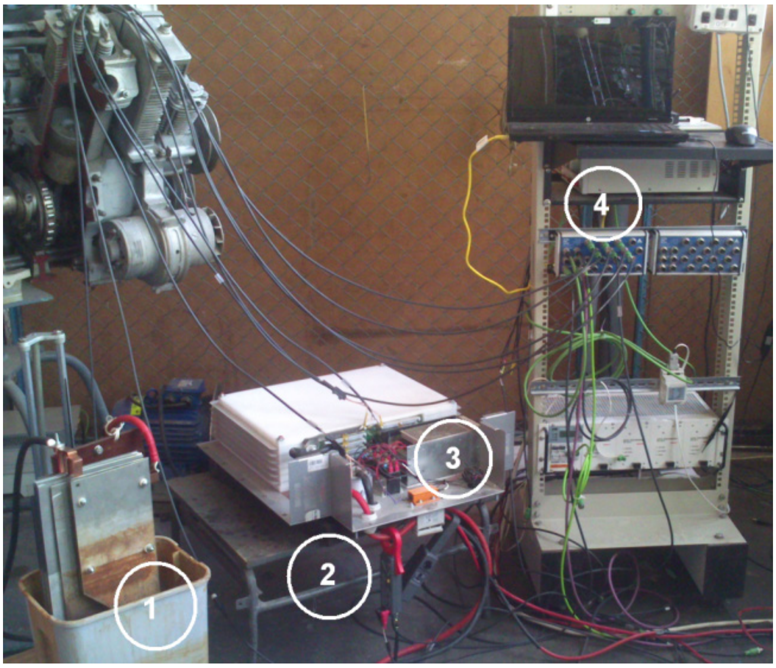

Fig. 1. Test stand for battery discharging: 1 – water resistor, 2 – current clamps, 3 – battery with voltage probes connected, 4 – acquisition computer with data logging card

3. Analysis of the battery test result

Test was performed for current of: 5 A, 10 A, 40 A, 60 A, 100 A and 150 A. The current values were match with respect to battery output current and water resistor output. Test for higher current values were difficult to performed, because of equipment parameters and safety matters. Received results meet data available from cells producer but do not contain voltage values in end range of battery operation. Investigation in end range, under 3.2 VDC is restricted because of battery management system, which shut down the battery main switch below this value to prevent damage by increased discharge.

Figure 2 show voltage in time function, depending on discharging current value. It might be observed that while current is increasing, time to emergency shut down by battery BMS is decreasing.

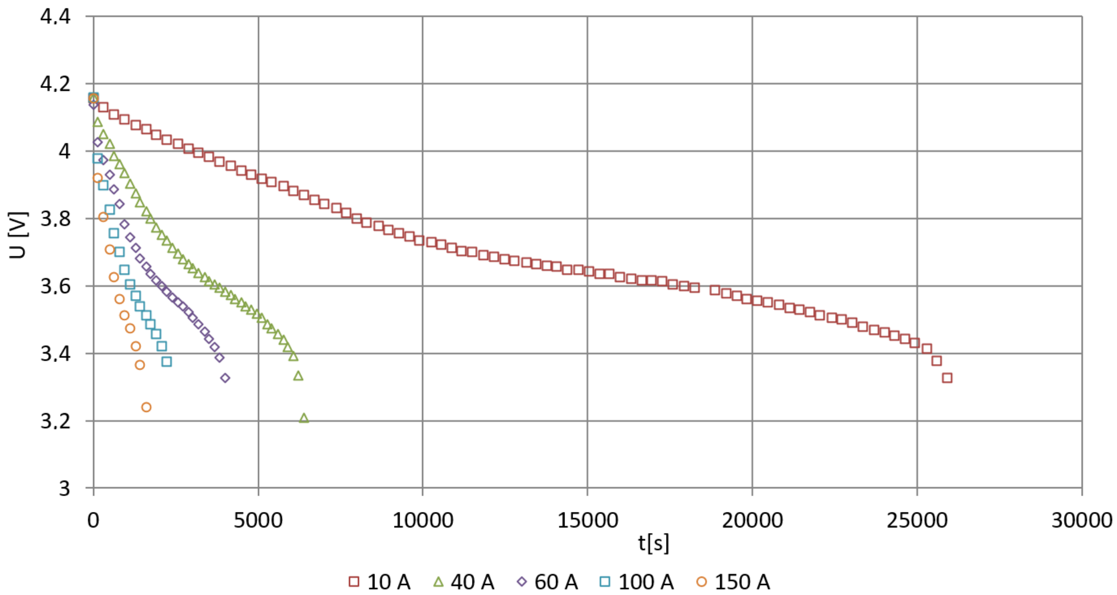

Fig. 2. Diagram of time discharging of the cell, depend on current current

State of charge of the battery was estimated according to parameters of battery supplier, BMS configuration and was shown in Tab. 1.

Tab. 1. State of charge of the cell, depending on the cell voltage

Cell voltage [V]	State of charge [%]
4.18	100
4.095	90
4.01	80
3.925	70
3.84	60
3.755	50
3.67	40
3.585	30
3.5	20
3.415	10
3.33	0

4. Model of battery test stand

The goal of the simulation analysis was to determine battery work on the design stage. Those simulations enable to verify preliminary calculations assumptions. This help to accelerate design of the small-unmanned vehicle's hybrid power transmission.

For that purpose, configuration of discharging stand, similar to configuration described above was made. This assembly consist of:

1) battery,
2) resistor,

3) current control loop,
4) discharging current set value.

Scheme of the stand and description of stand elements is shown on Fig. 3.

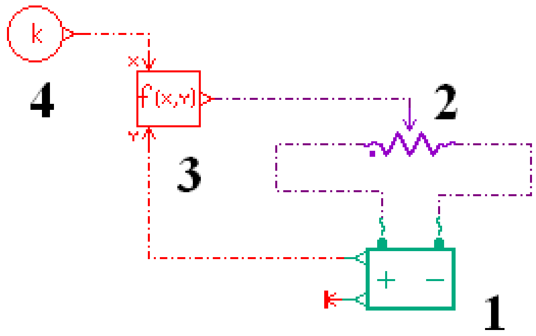

Fig. 3. Test stand modelled in AMESim software: 1 – battery, 2 – resistor, 3 – current loop, 4 – current set value

To model battery for the vehicle, parameters of single cells were needed. Battery consists of twelve SLPB 120216216KOKAM cells [8].

Simulation model of the battery represent his characteristic parameters such as capacity, number of cells, internal resistance, cell characteristics. On the basis of performed tests, characteristic curve, voltage depending of state of charge, of the single cell was elaborated (% SoC – State of Charge).

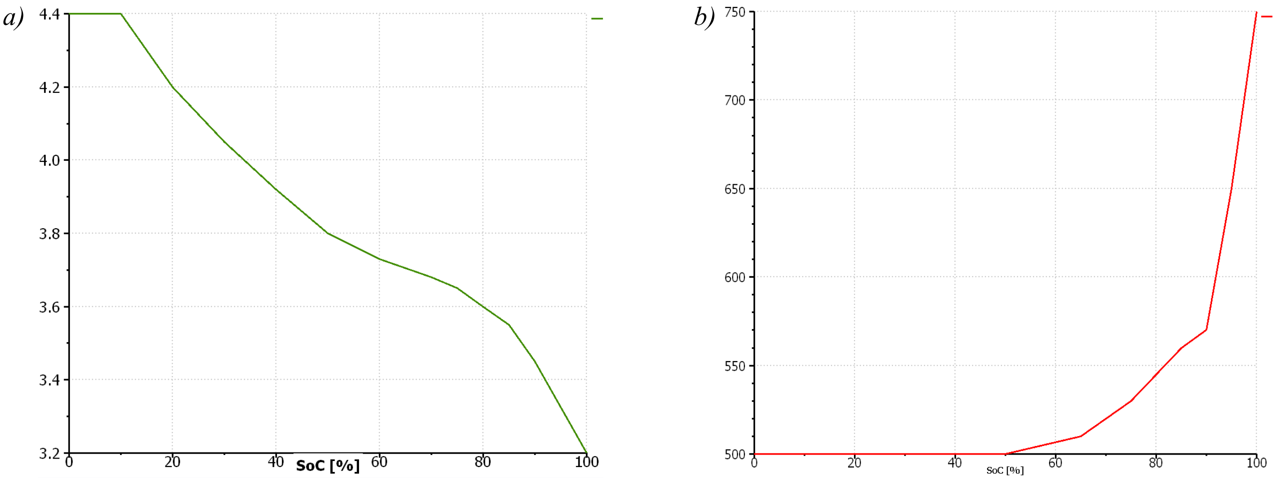

Fig. 4. KOKAM SLPB 120216216 cell state of charge modelled in AMESim software: a) voltage of battery, b) internal resistance of the cell

Battery consists of series connected cells. Software calculates capacity and voltage in a way shown on Fig. 5. Current source consist of four (Sbank) batteries connected in series and seven (Pbank) parallel. Number of cells connected in series of one battery is equal Ncell = 3.

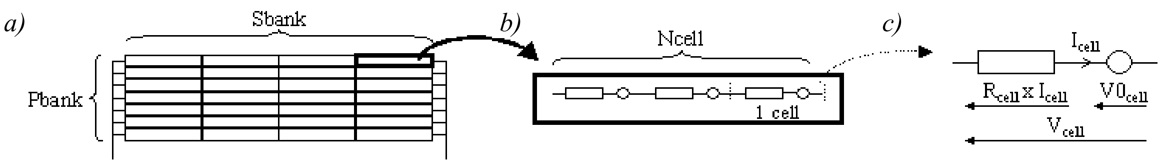

Fig. 5. Example of battery in AMESim, a) source of current consist of accumulators connected in series and parallel, b) battery consist of 3 cells, c) equivalent circuit of the cell, where I_{cell} – cell current; V_{cell} – cell voltage [1]

Open circuit voltage of the single cell (v0cell) and internal resistance of the single cell is read out from file. Data of file came from data acquired on a test stand and from cell producer. State of charge of the battery (% SOC) is a variable value, calculated from relation:

$$\frac{\mathrm{d}SOC}{\mathrm{d}t} = -\frac{\mathrm{d}q}{\mathrm{d}t} \cdot \frac{100}{C_{nom}}, \tag{1}$$

where:
C_{nom} – nominal capacity of the battery.

Output voltage of the single cell, V_{cell} [V], is calculated from relation:

$$V_{cell} = v0_{cell} - R_{cell} \cdot I_{cell}, \tag{2}$$

where:
$v0_{cell}$ – open circuit voltage of the cell,
R_{cell} – internal resistance of the cell,
I_{cell} – current of the cell.

Voltage on the positive pole of the battery is calculated the following:

$$V^{+} = V_{cell} \cdot N_{cell} \cdot S_{bank}. \tag{3}$$

5. Verification tests

For verification battery model, tests were made. The purpose of the test was to compare data from battery discharging test with battery model. During tests run in simulation software, currents values were similar to the values of discharging test performed on a test stand. Comparison results of simulation test data are shown on Fig. 6. Voltage values during test of 40 A and 150 A of discharging current are present. Parameters of the cell were adjusted to cell characteristics in a range, where it was possible to perform tests in respect to the BMS configuration. BMS shut down battery main switch when battery cells voltage drop to the 3.2 VDC.

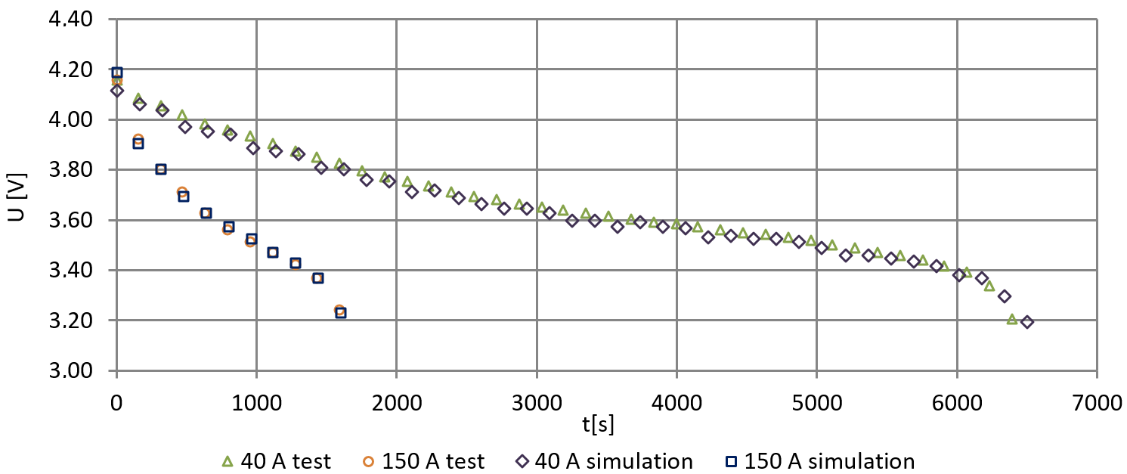

Fig. 6. Comparison battery characteristics with simulation model

On the Fig. 6 it can be seen that characteristic of the cell designed in simulation software is similar to the characteristic of the real battery cell. Voltage level on a single cell corresponds to the voltage on a cell used in simulation software, during discharging tests.

6. Conclusions

Performed tests on a stand enable to set characteristic of discharging cell and battery. Those characteristics could be used for model verification in simulation software.

Model of the single cell, battery and the test stand enable to design reliable battery model. This was possible because data from the real discharging test were used. Such a battery model can be used for simulation test of whole power transmission system of a hybrid vehicle.

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