Some Constraints on the Reuse of Li-ion Batteries in Data Centers

Costin Cepisca[1], Sabina Potlog[1], Sorin Dan Grigorescu[1], Marian Morcovescu[1]
[1]*Department of Measurements, Apparatus and Static Converters, University Politehnica, Splaiul Independentei 313, Bucharest, Romania*
costin.cepisca@gmail.com

***Abstract*— The development of rechargeable electrochemical sources, especially those based on Li-ion technology has opened the way to their use in various fields ranging from electronics and IT to electric cars. New ideas appear, such as using replaced batteries from electrical vehicles in the development of energy storage devices for critical consumers such as Data Centers. New uses impose detecting the unfavorable operating conditions which may endanger the power supply of Data Centers. This paper, by modeling and simulation, analyzes some particular problems of Li-ion batteries that appear due to the differences in state of charge of the cells.**

***Index Terms*—Circuit simulation; Li-ion batteries modeling; State of charge; Data Center**

I. Introduction

Different economic sectors have important needs related to the usage of rechargeable batteries. For example, consumer electronics use relatively small batteries with high energy density and low power. Other sectors, such as electric car industry, appeal to rechargeable sources with high capacity, high voltages that can produce high electric currents.

An overview of the opportunities for energy storage is presented in [1]; being considered lead batteries, nickel metal hybrid, lithium batteries and capacitors – Fig. 1.

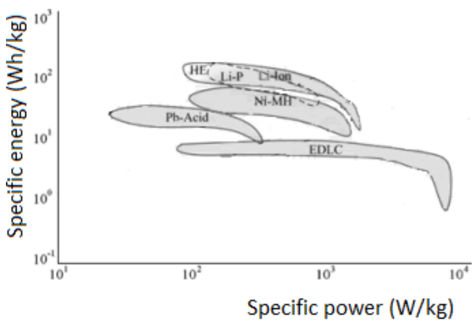

Fig.1. Energy storage technologies - specific power and energy

In applications, more than half of the turnover coming from the trade with batteries was made with the Li-ion battery type [2]. This battery requires little maintenance, has no "memory", self-discharge is lower than in other devices and it can power digital equipment directly due to the nominal voltage of 3.6 V cell, offering simplifications and thus cost savings. The cells of a battery can by connected in series (high voltage), parallel (high current) or mixed. The lifetime of these batteries used for electric vehicles is at least five years.

Lately there are new solutions for further use of Lithium batteries after removal from duty cycle to power electric vehicles and one of the proposed directions is to use them in complex systems for powering Data Centers, replacing UPSs [3]. By using a large number of partially degraded batteries used for electric vehicles, energy from renewable sources (photovoltaic, wind) can be stored in the Data Center, which helps reduce energy consumption from conventional networks. It is considered that this concept can be widely extended until 2020 and Li-ion batteries can find a new utility in Data Centers and also in household applications based on renewable energy.

The usage of these rechargeable batteries, partially worn must take into account the following aspects:

- In the process of charging the Li-ion cells the voltage must not exceed 4.2V; otherwise, damage may occur due to thermal effects and may even lead to fires;
- Exceeding the electrical values particular to the charging procedure leads to accelerated degradation of electrochemical phenomena and drastically reduces the lifetime [4]. For example, by increasing the charging voltage from 4.2 V to 4.25V, the degradation of the cell is 30%;
- Partial use of energy from the battery elements. If one of the cells reaches the required discharge limit, the protection system interrupts the discharge although the other cells are not discharged to the extent imposed.

The occurrence of voltage differences between the cells of a Li-ion battery or between the batteries that make up a power storage medium is a situation that can create difficulties. OCV (open circuit voltage) and internal of the battery cells depend on the State of Charge (SoC). [6].

Battery State of Charge (SOC) is defined as the ratio of the remaining capacity and the total capacity (Qn) of the battery:

$$SoC\,(\%) = \frac{Q_0 - \int_0^t i(t)\,dt}{Q_n} \qquad (1)$$

Here, Q_0 is the initial capacity of the battery and i(t) is the discharge current.

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The management of charging/discharging of these devices uses a continuous measurement of the voltage across the battery components. The values are an indication of the SoC of the batteries.[7].

This paper aims to realize modeling and simulations of Li-ion batteries in different states of charge to show the possible use of these batteries in the applications listed above and indicate the technical measures for the realization of the circuits.

II. Modelling of Li-ion Battery

The equivalent circuit for the Li-ion cell is done with resistors and capacitors - Fig.2. Resistor R_i models internal resistance and transient effects can be taken into account by the RC network [8]. Because our study analyzes the permanent working regime, the used model does not include the RC group [9].

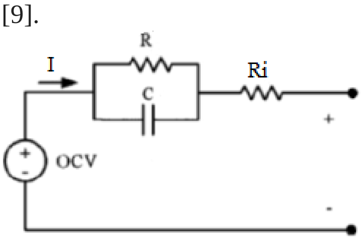
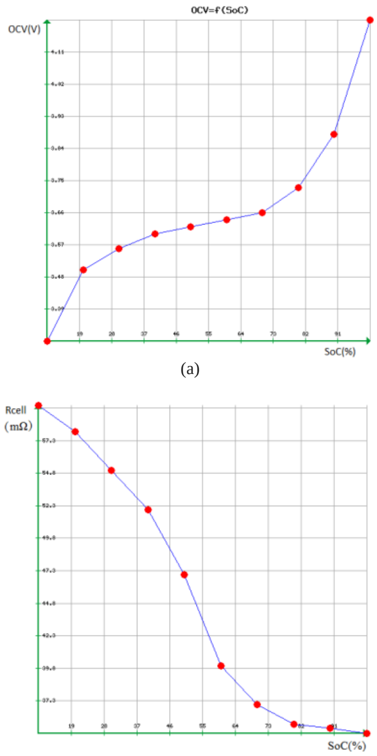


Fig.2. Thevenin model for Li-ion battery

According to technical data [10], [11], Fig. 3 indicates the OCV values and values of internal resistance R_i of the Li-ion cell at various states of charge. These values were used in the simulations described in this paper.



(b)

Fig.3. Variation of cell parameters: (a) OCV =f(SoC), (b) R_i = f(SoC)

III. Simulation Results

The battery taken into account in the considered study consists of eight parallel branches, each branch having 12 identical cells connected in series. The Fig. 4 shows battery model used and the possibility of changing the cell parameters with the values presented in Fig.3.

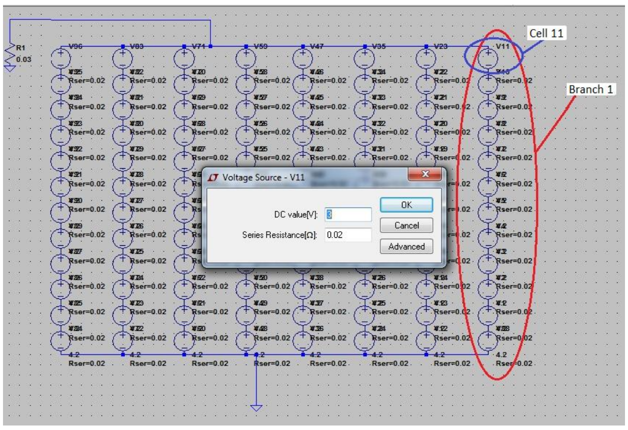


Fig.4. Battery modeling

Were studied following circuits made with varying degrees of load cells.

a) All cells charged SoC=100%

In this situation, the cell parameters considered were the following: OCV_{cell} =4.2V, R_i=0.0345Ω. Simulation result is shown in Fig.5. The voltage of the battery at no load operation was determined to be OCV= 50.4V. This circuit provides the highest voltage that can be obtained from the battery so configured.

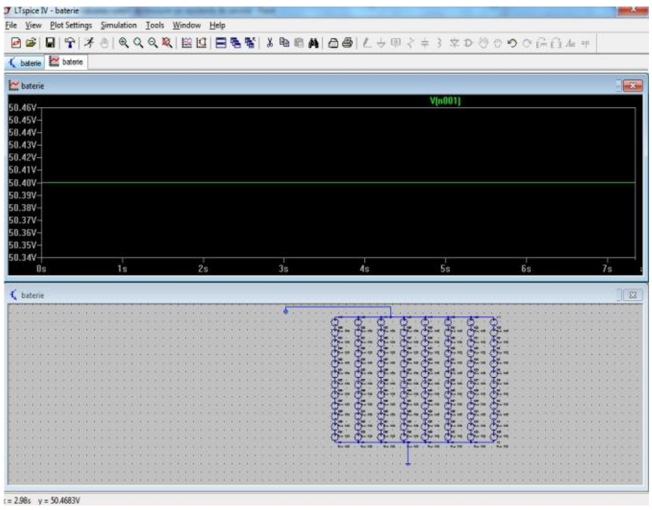
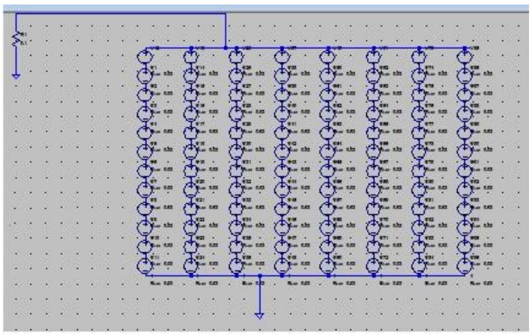
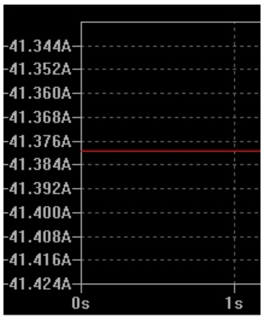


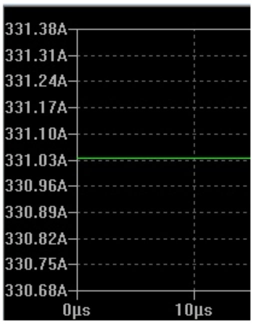
Fig.5. Battery voltage at no-load operation

By connecting a resistor R_{ext}= 0,1Ω to the battery terminals (Fig.6 a), the branch currents are 41,38A (Fig.6 b). The total current, given by the eight branches in parallel through the external resistor is 331,04A (Fig.6 c).



(a)





(b) (c)

Fig.6. Voltage and currents in the circuit for all cells SoC=100%

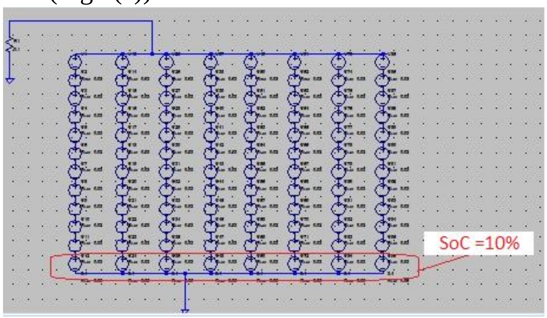
The powers in this case are:

- debited by the battery elements: P_t = 16.684 kW;
- in the external circuit: P_u =10.958 kW.

Only 65.7 % of the energy produced by the battery is transferred to the external circuit.

b) A cell with SoC =10% on each branch

Parameters of cell, with SoC=10%, are: OCV_{cell} =3.3V, R_i=0.06 Ω. Fig. 7(a) shows the new structure of the battery. The value of the current through a branch is 39.83A (Fig.7(b)) and the total current in the external circuit is 318.64A (Fig.7(c)).



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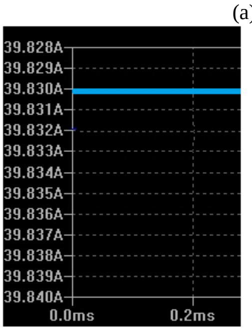
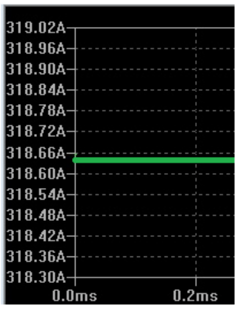




(b) (c)

Fig.7. Voltage and currents for a cell with SoC=10% on each branch

The presence of a discharged cell on each branch leads to a decrease in the total current from 331.04A to 318.64A and for output voltage from 33.10V to 31.86V.

The powers in this case are:

- debited by the battery elements: P_t = 15.758 kW;
- in the external circuit: P_u =10.153 kW.

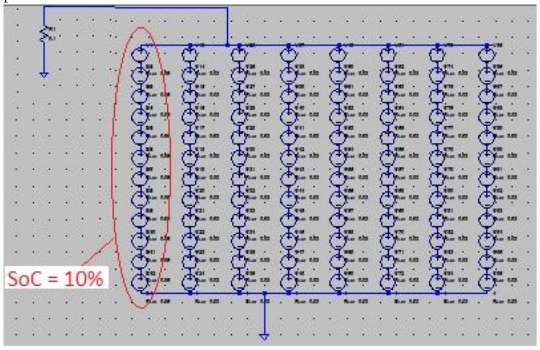
One can see a decrease of 6% in energy produced by the battery to the situation in which all cells were fully charged.

Only 64.4 % of the energy produced by the battery in this case is taken of external consumer, increasing the heating effect of the cells.

c) A branch with SoC=10% cells, seven branches with SoC=100% cells

The battery structure is shown in Fig.8(a). In this situation, in which an entire branch consists of discharged cells, the currents are presented in Fig.8(b). The current in the external circuit has a value 319.6A - Fig.8(c), the current in the branch with SoC=10% is 10.6A and in the regular branch the current is 44.14A.

The current through the branch with discharged cells is over four times lower than in branches containing cells fully charged. Similarly, the power sent to an external circuit by the branch with discharged cells P_d =388.7W is much smaller than that produced by a branch with fully charged cells P_f= 1410.7W.



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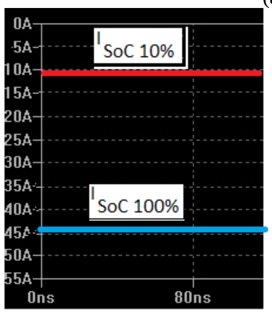
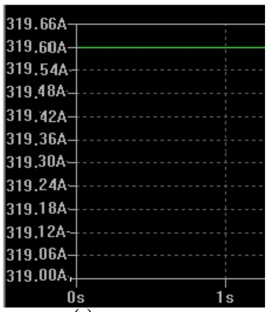




(b) (c)

Fig.8. Battery structure and currents for a branch with SoC=10% cells

The powers in this case are:

- debited by the battery elements: P_t = 15.992 kW;
- in the external circuit: P_u =10.214 kW.

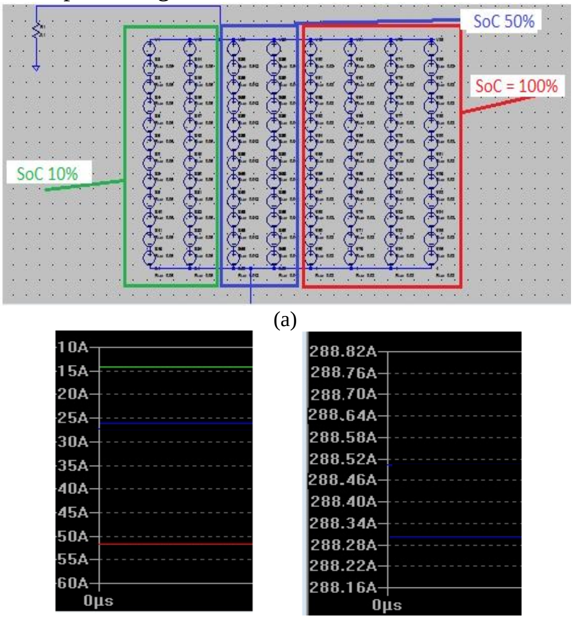
Only 63.8 % of the energy produced by the battery in this case is taken of external consumer, increasing the heating effect of the cells.

d) Battery has branches with different SoC

Fig.9 presents the results in the case of a battery containing branches with completely discharged SoC = 10% cells and SoC = 50% cells.

The current in the external circuit is 288.3 A - Fig.9(b). The current in the branch with SoC=10% is 14,46A, in the branch with SoC=50% the current is 25.9A and in the regular branch the current is 51.65A.

The existence of a discharged cell on the branches leads to a decrease in the total current from 331.04A to 288.3A and for output voltage from 33.10V to 28.83V.



(a)

(b) (c)

Fig.9. Battery structure and currents for various SoC cells

The powers in this case are:

- debited by the battery cells: $P_t = 13.808$ kW;
- in the external circuit: $P_u = 8.311$ kW.

Only 63.5 % of the energy produced by the battery in this case is taken of external consumer, increasing the heating effect of the cells. The power delivered to the external circuit drops to 90% of the nominal value of the battery with fully charged cells.

IV. Conclusions

Developing a Li-ion multiple cells batteries involves continuous monitoring of the cells electrical parameters, in order to assess its state of charge. Modeling and simulation results show that the difference in the state of charge of the component cells leads to a drop of the current in the external circuit and of the power. At the same time, heat dissipation on the internal resistances increases, leading to effects that can damage the battery.

A more complicated solution is envisaged for installations composed of used Li-ion batteries. In these cases, in addition to the differences between the battery cells, significant differences between the batteries that make up the construction may also occur.

In addition to a thorough study regarding the electrochemical phenomena in these situations, the need for sophisticated monitoring circuits, which ensure the operation of the battery assembly at optimal parameters, is taken into account.

Acknowledgment

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