ВЗАИМНО ВЛИЯНИЕ ОТ РАБОТАТА НА ПРЕОБРАЗУВАТЕЛИ В СИСТЕМА ЗА СЪХРАНЕНИЕ НА ЕЛЕКТРИЧЕСКА ЕНЕРГИЯ

MUTUAL INFLUENCES IN THE OPERATION OF CONVERTERS IN AN ELECTRICAL ENERGY STORAGE SYSTEM

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Abstract
This article studies the influence of simultaneous operation between a converter for charging a Li-Ion batteries and a converter for active voltage balancing (active BMS). The voltage equalizing system consists of resonant inverters with synchronous voltage doubler rectifier (SVDR) connected to their output. This system is applicable for batteries made of either Li-Ion cells or supercapacitor cells. Simulation model has been developed for the purpose of analysis of the converters.

Keywords: energy storage, voltage balancing, resonant converters, BMS.

ВЪВЕДЕНИЕ

Different active and passive voltage balancing methods are known for Li-Ion cells connected in series. [1, 2, 3, 4]. In active voltage balancing methods, a DC-DC convertors connected in parallel to each cell are used. The voltage at the input of the DC/DC converter has different potential than the voltage at its output. That's why the input of the converter is galvanically isolated from its output. One of the most commonly used circuits is a flyback converter [5].

For realization of a DC/DC converter, other circuits like a single ended resonant converter (SERC) can be used [6,7].

The most significant advantages of SERC are:

- Using only one power switching element working in ZVS and ZCS mode.
- Lower voltage drop due to the synchronous operation mode of the MOSFET rectifying transistors. Additional characteristics of this circuit are mentioned in [6,7].

There are two basic methods for voltage equalization. In the first method, the energy is taken from the whole battery pack and it is delivered to the cell with the lowest voltage. In the second method the energy is taken form the maximum charged cell and it is delivered to the whole battery pack.

In the proposed variant, the inputs of the DC/DC converters are connected in parallel. This causes the influence between the individual converters with respect to their inputs.

On the other hand the converters work along with the main charging converter with common load (the charging cells). This causes the influence between the converters with respect to their outputs.

That influences has to be considered when this circuit is being designed.

Other methods are also known for voltage balancing across energy storage cells connected in series. [8, 9, 10].

BLOCK DIAGRAM

Fig. 1 shows the block diagram of the system for charging and voltage equalization across Li-Ion cells connected in series.

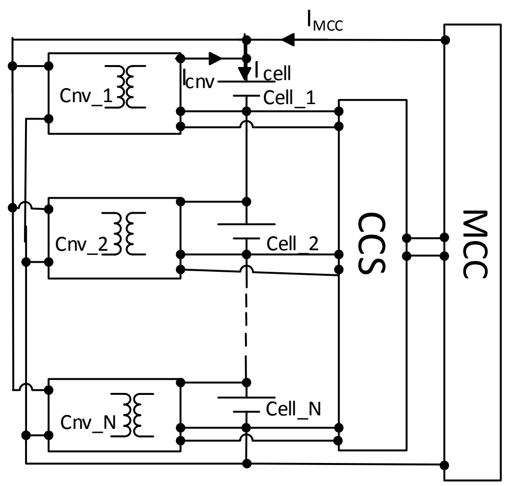

Fig. 1. *Block diagram of the charging system*

The research is done for battery pack made of 10 Li-Ion cells connected in series. In the block diagram they are marked as Cell_1 to Cell_N. The blocks marked as Cnv_1 to Cnv_N are DC/DC converters (SERC with SVDR described above). The block marked as MCC is DC/DC converter working in current source mode. It makes CC and CV modes for charging the battery pack. The block marked as CCS is central control system and it is used to control the MCC and the converters Cnv_1 to Cnv_N.

WORKING ALGORITHM

Before starting the process of charging, the system determines the capacitance of the each individual cell by measuring the voltage variation of each cell. This is done by discharging the whole battery pack for a very short period of time. After determination the capacitance for each cell by using some of the well-known methods [6,7], the main charging process is started. The charging current for each cell is a sum of the current of the MCC and the current of the respective to each cell DC/DC converter.

Icell = Imcc+Icnv.N (1)

The current Icnv for each DC/DC converter is determined with respect to the capacitances of each cell. The current Icell must not exceed the maximum possible current for the cell. The current Icnv is determined on the base of the capacitance of the particular cell and the capacitance of the rest of the cells. The current for each DC/DC converter will be different. The current from the MCC is given by the next equation:

Imcc = Icellmax - Icnvmax (2)

where:
Icellmax – the maximum possible current for the cell;
Icnvmac – the maximum current for the converter;

When the charging process is started, MCC and the converters Cnv_1 to Cnv_10 work simultaneously with different output currents. The time of simultaneous working for all converters is calculated with so called method of predictive control. After this time, each individual cell will be at different state of charge. The cells with higher capacitance will have higher SOC than the cells with lower capacitance. After that, the charging of the battery is done only by the MCC. The charging current for all cells connected in series is one and the same. This current is equal to the maximum possible current for one cell. When the currents Icnv_1 to Icnv_N are determined correctly, the individual cells will be charged to different voltage levels in such way that at the end of the charging process the voltages on the cells will be equal. From the described algorithm can be seen that there is a moment that all DC/DC converters work simultaneously. This paper studies exactly this period of time.

SIMULATION MODEL

On Fig.2 is shown an LTspice simulation model of the described above charging system. This is developed version of the circuit shown in [6,7].

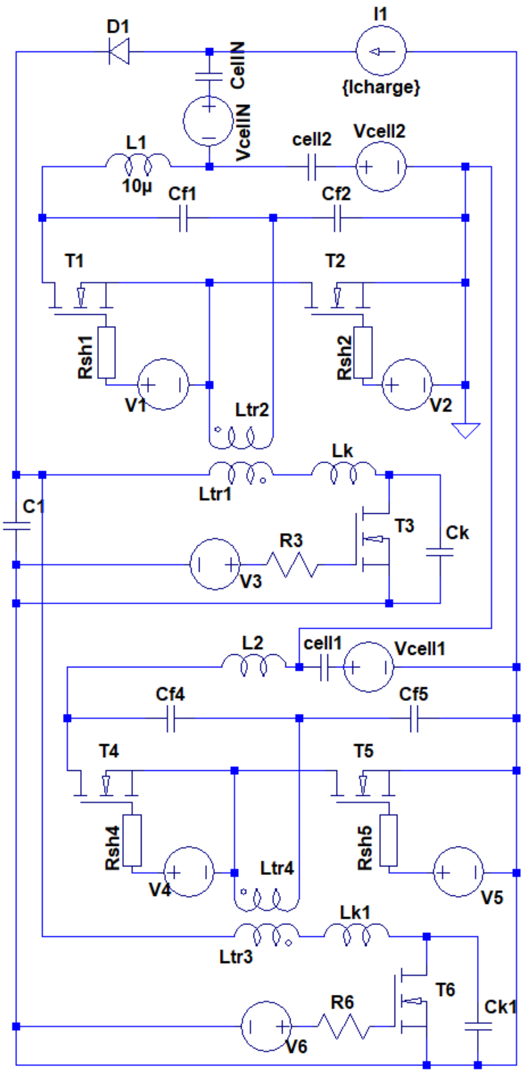

Fig. 2*. Simulation model*

In this model is assumed that two cells (Cell_1 and Cell_2) will have different capacitance. So they have to be charged to different voltage levels. The rest 8 sells are represented by one supercapacitor cell marked as Cell_N which has the equivalent capacitance of 8 supercapacitor cells connected in series.

The main charging converter is represented by constant current source I_1.

In this simulation model, the capacitance of the supercapacitor cells is highly reduced only for purpose of faster simulation process.

Parameters of the elements used in this simulation are as follows:

- Cell_1 = 0.8F, Cell_2 = 1.2F
- Cell_N = 0.125F
- $C_{f_1} = C_{f_2} = 100\mu F$
- $C_k = 0.1\mu F$
- $L_k = 75\mu H$
- $V_d = 42V$
- Transformer ratio is 2.13.
- The transformer coupling is 0.995

In this simulation model, the battery cells are represented by combination of voltage source and supercapacitor. The voltage source represents the initial voltage of the cell and the supercapacitor represents the remaining capacitance of the cell. In Fig.2 these are Cell2 with Vcell2 and Cell1 with Vsell1.

The voltage sources V_1, V_2, V_4 and V_5 represent the control systems (CS) for the rectifying transistors T_1, T_2, T_4 and T_5 and ensures synchronous operation* with ZCS and/or ZVS working mode for these transistors.

SIMULATION RESULTS

Fig.3 shows the voltage across two cells from the battery pack and currents through the outputs of the converters - I(L1) и I(L2).

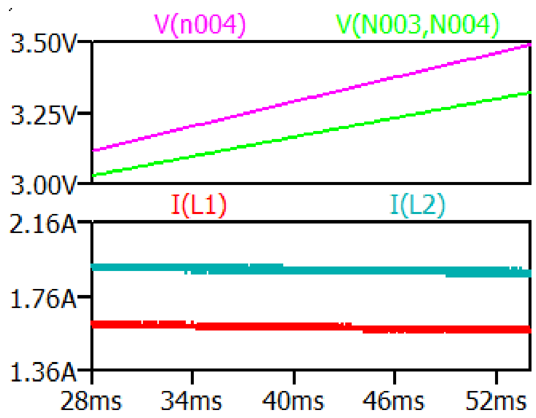

Fig. 3*. Voltage across two cells*

Fig. 4 and fig. 5 shows the voltages across two of the cells cell1 – V(n004) and cell2 – V(N003,N004) and the currents at the output of the converters Cnv_1 – I(L1) and Cnv_2 I(L2) used for voltage balancing .

Fig. 4 shows voltage and current time diagrams for the transistors T6 and T3. As it can be seen, both converters work with ZVS and ZCS mode. For getting different output currents for the both converters, the transistors T3 and T6 are turned on for different time intervals. To keep ZVS working mode, the operating frequency of the converter needs to be changed which means that the two convertors work with different operating frequencies.

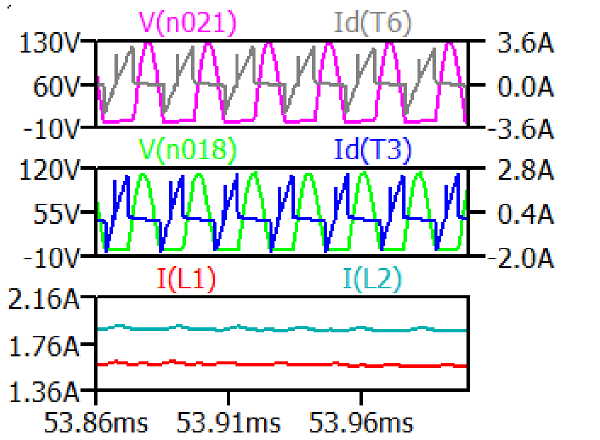

***Fig. 4**. Voltage and current for transistors T6 and T3*

Fig. 5 shows the voltage and the current time diagrams for the synchronous rectifying transistors T1 and T2.

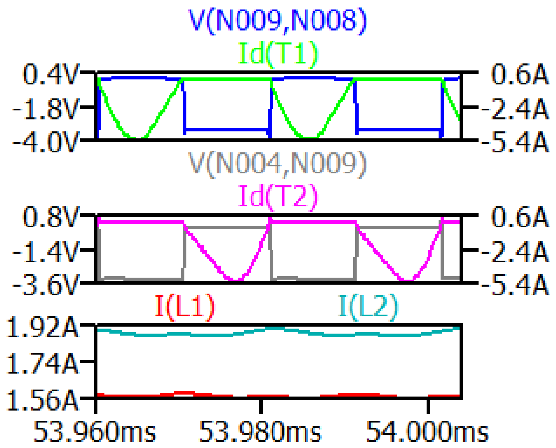

***Fig. 5**. Voltage and current for transistors T1 and T2*

Fig. 6 shows the current time diagrams for the resonant inductances Lk1 I Lk1.

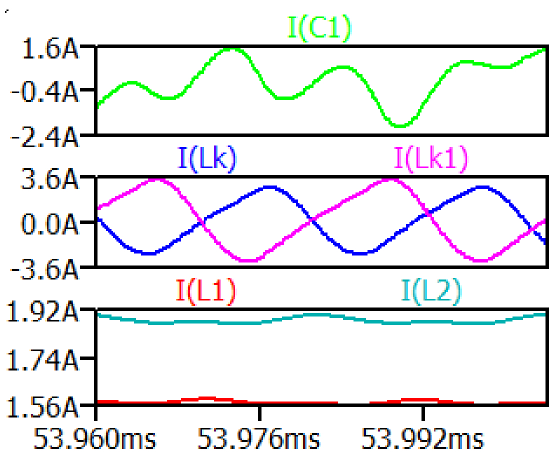

***Fig. 6**. Current through the inductances Lk1 I Lk1*

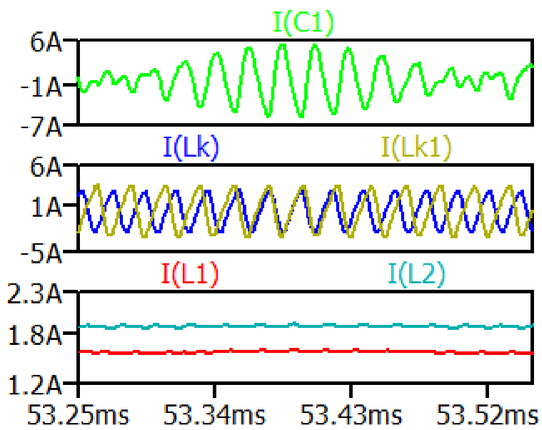

***Fig. 7**. Current through the inductances Lk1 I Lk1*

Fig. 7 shows again the currents through the resonant inductances Lk1 I Lk1 and the current through the input capacitor C1. It can be seen that the maximum value of the current through this capacitor changes. This is due to the different frequencies of the driving signals for the two converters. In simultaneous working of more than two converters, this current has high harmonic spectrum. This have to be considered when this capacitor is being chosen.

CONCLUSION

It is studied the influence of simultaneous work of the converters for charging and equalizing the voltages across Li-Ion cells, connected in series. It is developed a BMS model. Software simulation of the working of the convertors is done.

From the results can be seen that with the proposed algorithm the simultaneous working of the convertors is possible. The influence between the converters is with respect to the input power source. This influence is insignificant and the charging system can operate normal.

The proposed algorithm for voltage balancing is applicable not only in the case when the supplying for the converters Cnv_1 to Cnv_N is taken from the battery itself but also when the supplying is taken from the main energy source.

Half bridge driver circuits can be used for controlling the synchronous rectifiers. The supplying for this drivers can be delivered by using third auxiliary winding of the transformer. It is enough to be used half wave rectifier, connected to this winding. The disadvantage of this method is that when the voltage of the charging cell changes between 2.7 and 4.2 volts, the voltage from the auxiliary winding also changes. (the auxiliary winding is not shown) This also need to be considered when a BMS with such topology is being designed.

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