

## SIMULATION OF A BATTERY MANAGEMENT SYSTEM BASED ON SWITCHING CAPACITORS

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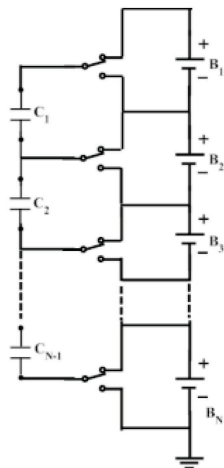
### Abstract

In this work, a simulation model of battery management system (BMS) is developed. A switched capacitor system is used to balance the voltages. Results are presented to demonstrate the balancing process at different initial Li-ion cell voltage values. Results are presented for the switch currents and voltages switching the switched capacitors between the individual cells.

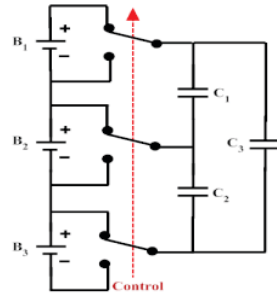
**Keywords:** battery management system, switching capacitors, modeling, PLECS.

### INTRODUCTION

Various passive and active methods are used to balance the voltages of series-connected Li-ion cells. One of them is based on energy transfer between cells [1]. Different circuits with switched capacitors are used [2, 3, 4, 5, 6]. Two of the basic circuits are shown in Figure 1 and Figure 2.



**Fig. 1.** Basic switched capacitor [3].

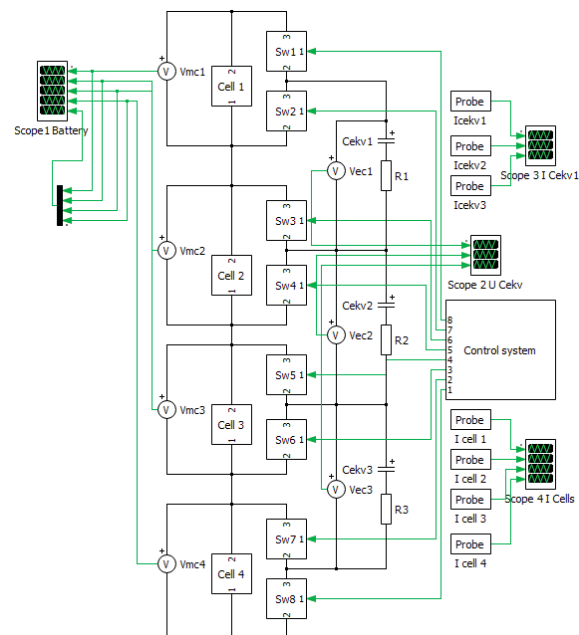


**Fig. 2.** Double tired switched capacitor [3].

The circuits shown above can also be used for voltage balancing of series connected supercapacitors. Other variations of active balancing are also used for voltage balancing [7, 8, 9].

### SIMULATON MODEL

A simulation model (Figure 3) was developed [11] based on the basic circuit shown in Figure 2. The switching capacitors which equalize the cell voltages are implemented with MOS transistors. They are shown as blocks Sw1÷Sw8.



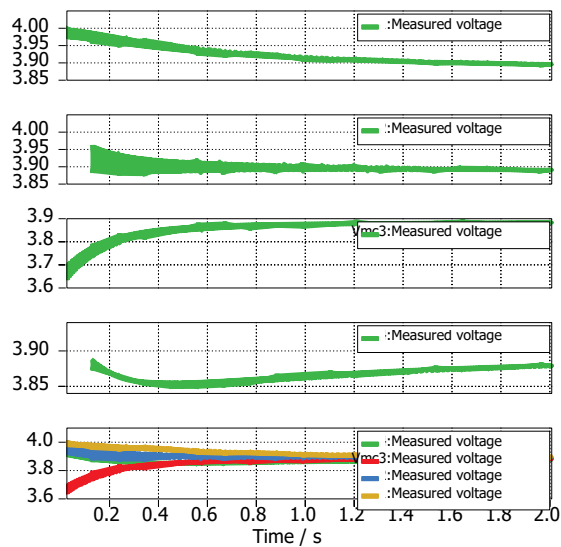
**Fig. 3.** Simulation model [11].

The connection of the transistors in these blocks is given in [11]. The Cell 1 ÷ Cell 4

blocks are simplified models of Li-ion cells as the cell capacitances are significantly reduced to visualize the processes for smaller simulation times. The cells Cekv1÷Cekv3 are the switched capacitors with which the equalization is performed. The resistances R1÷R3 reflect the equivalent resistances of the connecting wires and the internal resistances of the capacitors.

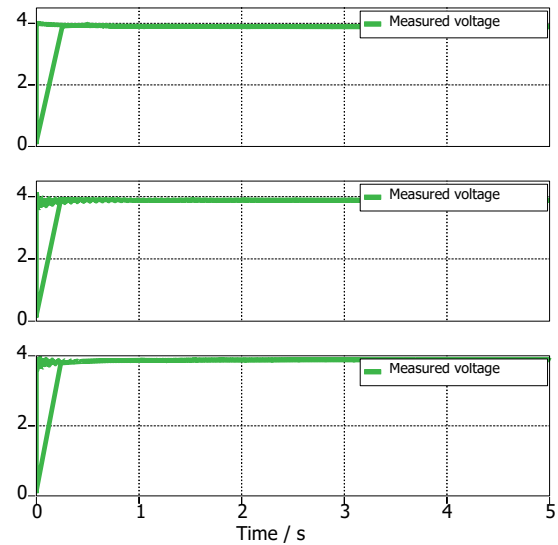
In the simulation model, 4 blocks have been added to visualize currents and voltages in the simulated system.

Figure 4 shows the time diagrams for the voltages on each of the Li-ion cells. The voltages Vmc1÷ Vmc4 are the voltages on the four cells. They are set with different initial values. The initial values are 4V, 4V, 3.95V and 3.6V. The fifth diagram presents the results for the voltages together. It shows the equalization of the voltages after some time.



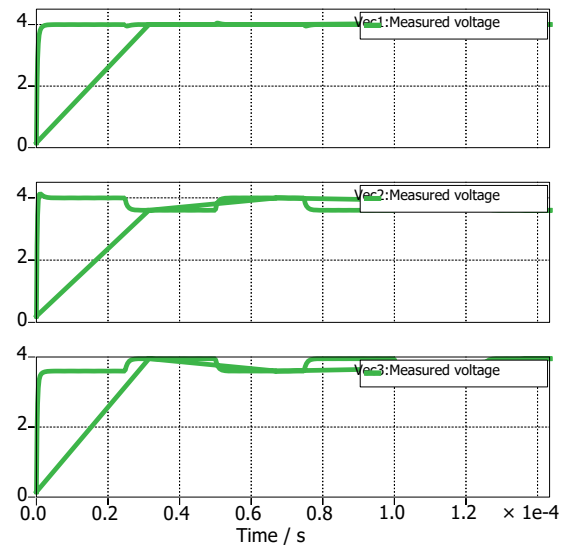
**Fig. 4.** Simulation results. Voltage across the cells

Figure 5 shows the time diagrams of the voltages on the capacitors (Cekv1-Cekv3) doing the voltage equalization. These time-diagrams also show the initial establishment of the voltages on the switched capacitors, which occurs once when the BMS is connected to the battery cells.



**Fig. 5.** Simulation results. Voltage across the switching capacitors.

Figure 6 shows results similar to those in Figure 5, but enlarged to demonstrate the change in voltage across them during the switching process.

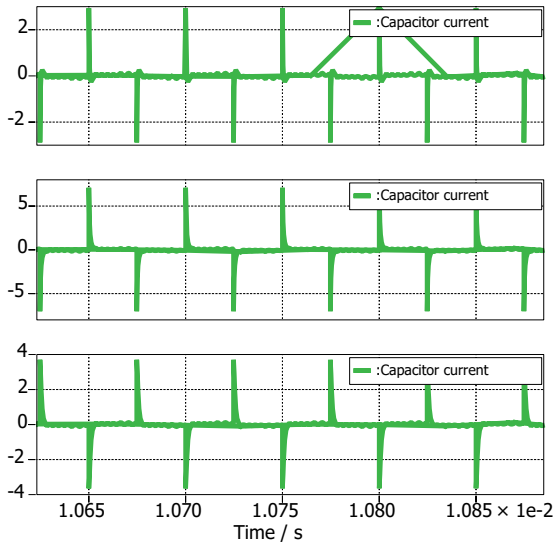


**Fig. 6.** Simulation results. Voltage across the switching capacitors.

The switching frequency is chosen low enough to allow the voltages to be established after the corresponding switching.

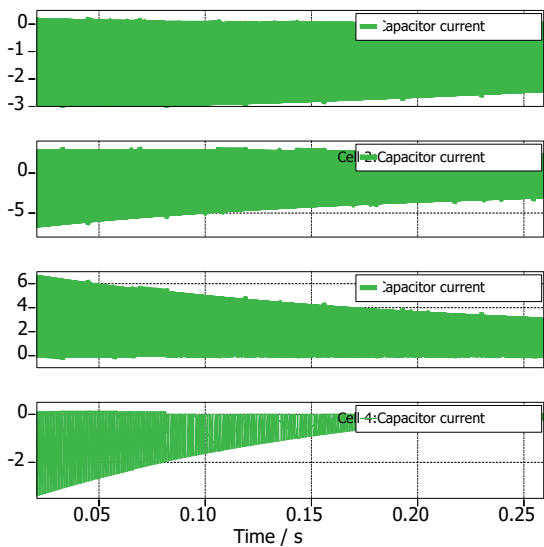
Figure 7 shows the currents through the switched capacitors at the beginning of the voltage equalization process on Li-ion cells.

In the equalization process, these currents decrease and the voltage equalization process slows down accordingly.



**Fig. 7.** Simulation results. Current through the switching capacitors.

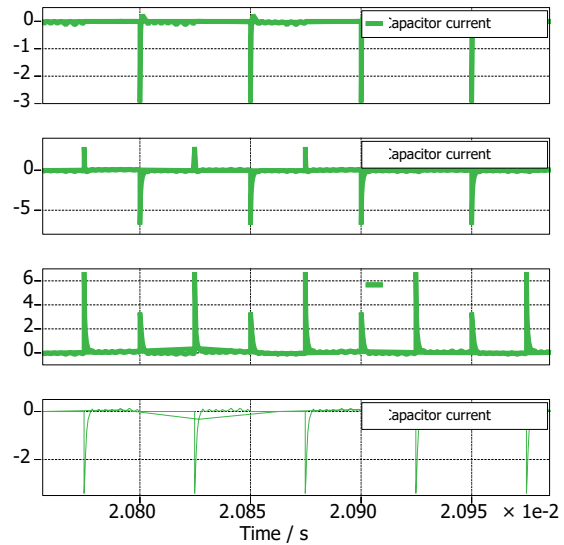
Figure 8 shows the currents through Li-ion cells in the equalization process. It can be seen from the diagrams that these currents flow through some of the cells in both directions.



**Fig. 8.** Simulation results. Current through the Li-ion cells.

Figure 9 shows the currents through the Li-ion cells again, but enlarged to see their shape in more detail. A snapshot of the beginning of the equalization process is

presented to highlight the peak currents through the elements.



**Fig. 9.** Simulation results. Current through the Li-ion cells.

The direction of the currents can be used to analyse how the energy transfer takes place. For example, for a given interval, it can be seen that cell 2 is charged and discharged at every two consecutive switchings.

## CONCLUSION

A BMS simulation model has been developed for four Li-ion cells with three switched capacitors. It can be used to monitor the system currents and voltages under different cell initial conditions. The timing diagrams shown are in a mode where all switches are switched simultaneously. By investigating with this model, the loads on the switches, switched capacitors and Li-ion cells can be evaluated. Similar results were obtained from an experimental model running this scheme and algorithm.

From the illustration of the processes, it can be concluded that with this form of current through Li-ion cells, the operation of the analog-to-digital converter to measure the voltages of each cell will be difficult. In this case, it will be necessary to stop the equalization process briefly to make the measurements. The developed

simulation model allows to evaluate the advantages and disadvantages of this type of equalization system. If the voltage equalization scheme used above is applied to supercapacitors, then a model developed for the software used can also be used [10].

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