Multicriterial evaluation and optimization of an algorithm for charging energy storage elements

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Abstract—**This study compares optimized active voltage balancing algorithms, applicable for energy storage systems made of supercapacitor cells connected in series. The results presented herein are obtained from a simulation model and confirmed on an experimental stand.**

I. Introduction

NOWADAYS, the most widely used elements for energy storage systems (ESS) are either Li-Ion cells or Supercapacitor cells. The control system or the Battery Management System (BMS) [1] has the task to charge and discharge them and manufactured a battery pack without any damage due to over voltages or over currents. Nowadays all BMSs use active voltage balancing techniques based on different methods [2]–[7].

II. A SHORT DESCRIPTION OF THE STUDIED ENERGY STORAGE SYSTEM

A simplified block diagram of the studied energy storage system (ESS) is shown in Fig. 1.

The DC/DC converters linked in parallel to each cell are additional charging sources (ACS). The DC/DC converter linked in parallel to the whole string is a main charging source (MCS). I_{main} is the main charging current. It charges the whole battery module. I_{add} is an additional charging current. I_{cell} is the cell charging current. For more details see [8], [9]. We stress on the fact that the simulations use technical information for 58F/16V module supercapacitor by Maxwell Technologies Inc. [10]. t_{fch} is the time necessary for the cell
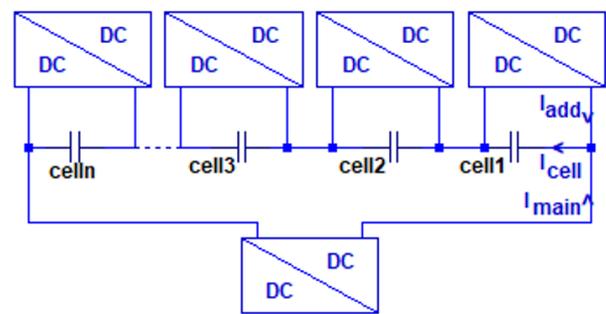
Fig. 1. ESS block diagram

with the highest capacitance C_{max} to charge from its initial voltage up to its rated voltage. It is described as

$$t_{fch} = f(C_{max}, I_{max}, \triangle U_{(C_{max})}). \tag{1}$$

III. THE BASIC ALGORITHM

In the basic algorithm (BASIC) the charging current is less than the maximum charging current I_{max}.

$$I_{cell} = I_{main} + I_{add} < I_{max} \tag{2}$$

I_{main} and I_{add} are strictly fixed. For each cell C_n and I_{add} is different and depends on the capacitance of the cell. I_{main} is given by:

$$I_{main} = I_{max}.C_{min}/C_{max}, [A] \tag{3}$$

I_{add} is given by:

$$I_{ACC} = I_{max}.((C_n - C_{min})/C_{max}), [A] \tag{4}$$

Here I_{max} is the maximum charging current. C_n is the capacitance of the n-th cell. C_{min} is the lowest capacitance and C_{max} is the highest capacitance. A detailed description of this algorithm can be found in [11]. Fig. 2 shows a typical charging process by using this algorithm.
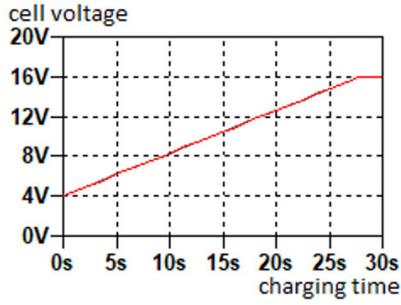
Fig. 2. Voltages across cells during charging

IV. THE OPTIMIZED ALGORITHM

The second algorithm (OPTIMIZED) is optimized because it has a value $\triangle U$ of the voltage. It cannot be changed indefinitely. There are some optimal values, which, if skipped, result in other phenomena. Also some limit values for which the algorithm works optimally can be mentioned. Thats why for the future work we will make a 3D visualization, as a dependence on several quantities and to show their optimal value. The description of the optimized algorithm is described below. We begin by loading all the cells with a maximum charging current, being achieved through the synchronized work of the MCS and all ACSs which currents are equal. The charging current for each cell is:

$$I_{cell} = I_{main} + I_{add} = I_{max} \qquad (5)$$

A detailed description of this algorithm can be found in [12]. Fig. 3 shows a typical charging process by using this algorithm.
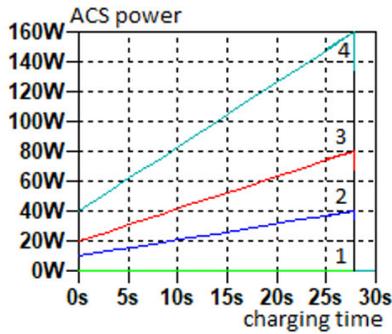

Fig. 3. Cell voltages during charging

The key point of the OPTIMIZED method is turning the ACSs off one after another and loaded the cells only by the MCS. For each cell C_n there is a specific moment $t_{x(C_n)}$ when its ACS is turned off. For the time from $t_{x(C_n)}$ to t_f, the charging current is provided only from the MCS. The specific for each cell moment t_x is given by:

$$t_x = t_{fch} \cdot [I_{main}/I_{add} \cdot (C_n/C_{max} - 1) + C_n/C_{max}] \qquad (6)$$

On Fig. 4 it is shown what happens when the capacitance difference changes.
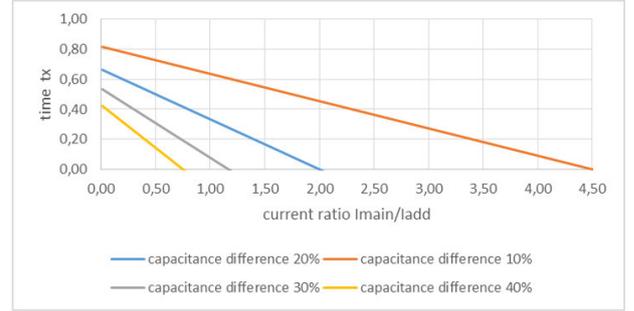
Fig. 4. t_x as a function of β

V. SIMULATION RESULTS AND COMPARISON OF THE STUDIED ALGORITHMS

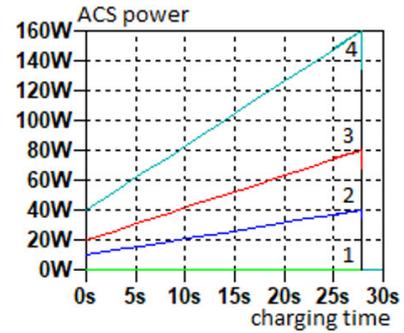On Fig. 5 it is shown how the power of the additional charging sources changes.

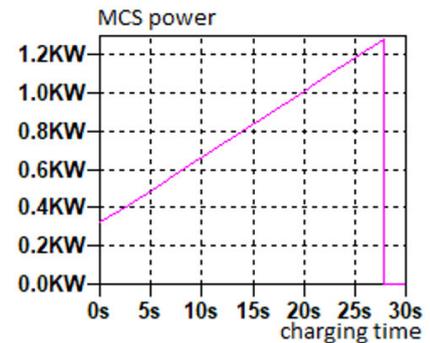Fig. 5. ACS power

On Fig. 6 it is shown the power of the MCS.

Fig. 6. MCS power

On Fig. 7 it is shown how the power of the ACSs changes during the process of charging.

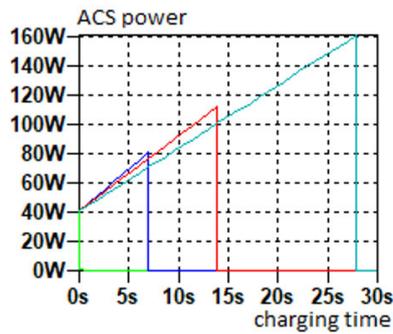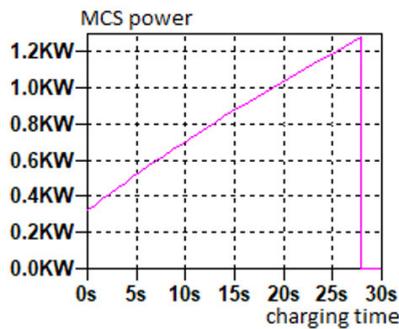Fig. 8 shows the power of the main charging source.

Fig. 7. ACS power

Fig. 8. MCS power

The summarized data are shown below. The notation b is for the BASIC algorithm and o is for the OPTIMIZED algorithm. The OPTIMIZED method gives better results for the sources. Table 1 shows calculated values for daily mean value of consumed energy and its statistical characteristics -– standard deviation, coefficient of variation, and confidence intervals at 0.95 confidence probability, where: P_a -– an average power;

TABLE I

source	Pa[W],b	Pa[W],o	Pp[W],b	Pp[W],o	E[J],b	E[J],o
ACS1	0	0	0	0	0	0
ACS2	25	60	40	80	696	422
ACS3	50	77	80	113	1392	1066
ACS4	100	101	160	160	2784	2800
MCS	800	827	1280	1282	22272	23019

P_p — a peak power; E -– the energy;

VI. CONCLUSION

In the BASIC algorithm, the main charging current is fixed as a function of the cell with the lowest capacitance. A key element in the OPTIMIZED algorithm has the capacitance difference between the capacitor with the highest capacitance and the capacitor with the lowest capacitance. For the future work we will make a 3D visualization, as a dependence on several quantities and to show their optimal value.

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