Low-Voltage-To-Cell Battery Management System

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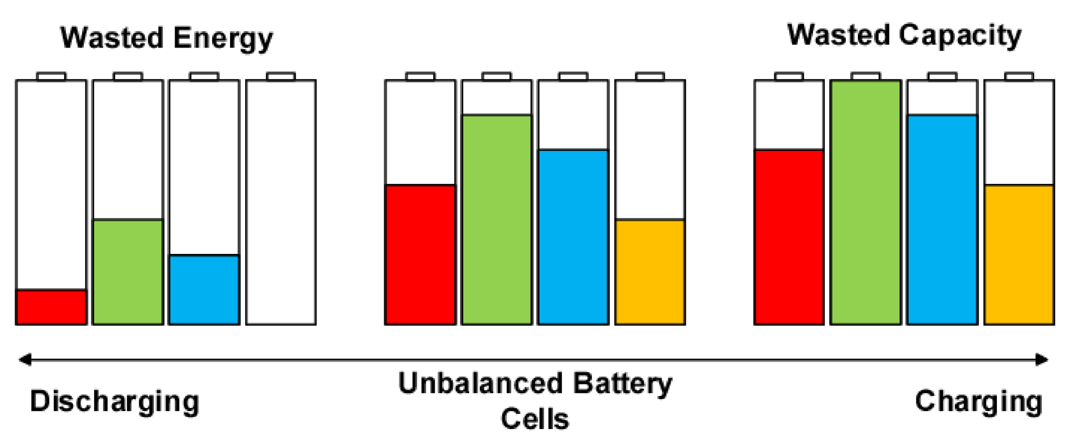
EECOMOBILITY (ORF) & HEVPD&D CREATE

OBJECTIVES

Motivation

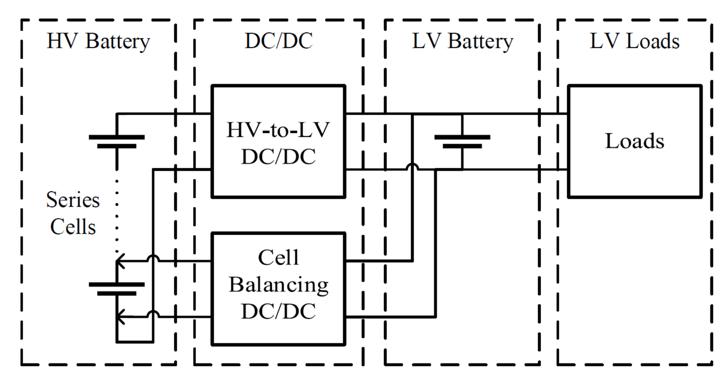
A high voltage battery pack will have weaker cells due to manufacturing impurities, temperature gradients, self-discharge rates or mechanical constraints. These differences will eventually manifest as cell-to-cell differences in energy capacity, and will generally amplify over time from cycling the pack. Thus, all high voltage battery packs require cell balancing circuits to protect the cells during charging and/or discharging. This is critical for taking advantage of the full capacity of the pack.



ARCHITECTURE

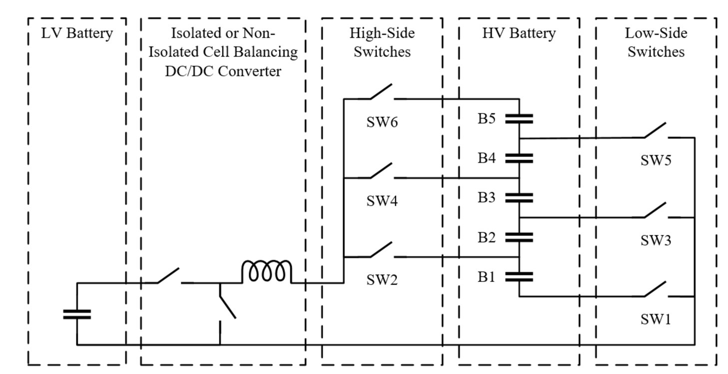
System

The proposed low-voltage-to-cell (LV2C) system architecture can be seen below. The low voltage battery is used to allow quick sourcing or sinking of current needed by the cell balancing DC/DC converter. Balancing times of non-adjacent cells can be reduced since the charge is not shuttled through the stack.



Circuit

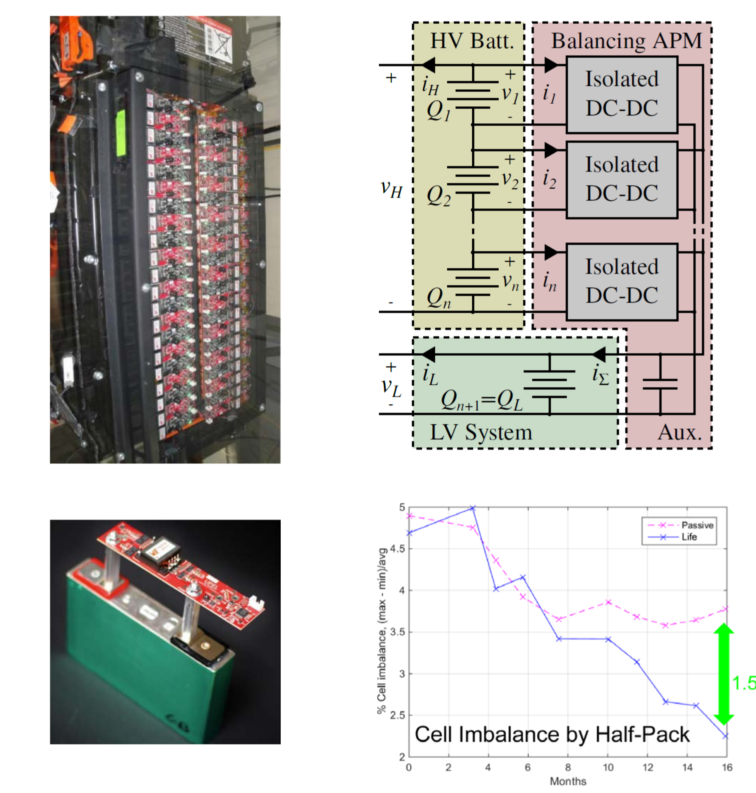
A bi-directional cell balancing DC/DC converter is used to source and sink current in both directions, allowing for precise control. The proposed circuit controller can select the cell to be charged or discharged. Odd cells can be discharged directly, while even cells must be used in stacks of three.



STATE-OF-THE-ART

Life Balancing

Anderson *et al.* proposed that the low voltage battery should be connected to the cells through an isolated DC/DC converter. This would replace the traditional auxiliary power module in electric vehicles with many smaller converters, reducing the voltage rating of the switches. It would achieve a faster cell balancing time due to the ability to control the current of each cell. However, this technique requires a circuit board the size of one side of an entire battery pack.



M. Evzelman, M. Muneeb Ur Rehman, K. Hathaway, R. Zane, D. Costinett and D. Maksimovic, "Active Balancing for Electric Vehicles With Incorporated Low-Votlage Bus," *IEEE Transactions on Power Electronics*, vol. 31, no. 11, pp. 7887-7895, November 2016.

COMPARISONS

Components

The cost and complexity of a balancing circuit is primarily affected by the number of inductors and switches present. Keeping these components at a minimum helps to make the design more feasible for use in commercial vehicles. Modularity is also an important feature.

Hardware-Efficient

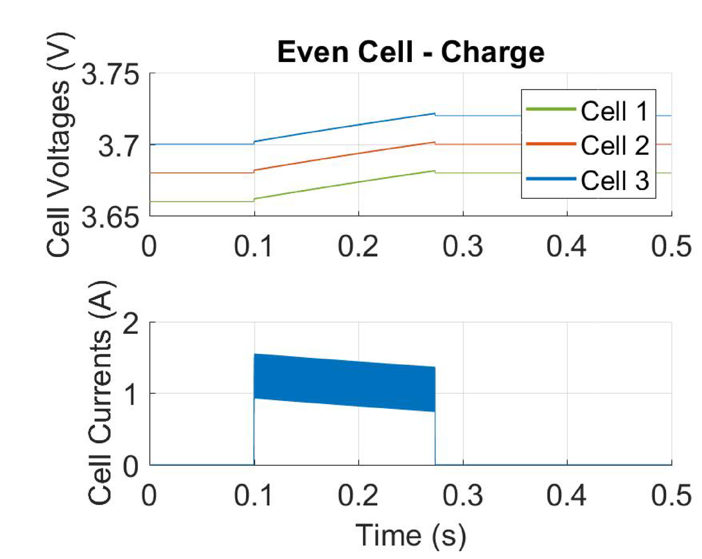
For a stack of *n* cells in series and m modules, the proposed architecture uses *n+1* bilateral switches to select the cell. There are m DC/DC converters with m inductors and 2m switches to perform the balancing operation.

Cell Balancing Techniques		Passive Cell Balancing	Active Cell Balancing										
			Cell-to-Cell						Pack-to-Cell			Low Voltage	
			Direct		Adjacent								
Items		Dissipative Resistor	Single Inductor	Coupled Inductor	Switched Capacitor	Cuk based Converter	Unidirect. Buck-Boost	Bidirect. Buck-Boost	Multiple Transformer	Multi-Winding	Switched Transformer	Life Balancing	Proposed System
Switch	#	N	2N	2N	2N	2(N+1)	N	2(N-1)	N	N	4N+1	2N	2(N+1)
	Stress	V_B	NV_B	$2V_B$	$2V_B$	$2V_B$	$2V_B$	$2V_B$	$2V_B$	$2V_B$	NV_B	$2V_B$	$8V_B$
Diode	#	0	2N	0	0	0	N	0	N	1	1	N	0
	Stress	-	NV_B	-	-	-	$2V_B$	-	NV_B	NV_B	$2V_B$	V_B	-
Inductor		0	1	0	0	2(N-1)	N	N-1	0	0	0	N	8
Transformer [#]		0	0	1 [N/2]	0	0	0	0	N [2]	1 [N+1]	1 [2]	0	0
Capacitor		0	0	0	N-1	N	0	0	0	0	0	N	8
Size/Weight		E	VG	G	E	S	G	G	P	S	VG	P	S
Control Simplicity		E	S	P	E	G	VG	G	VG	E	G	P	P
Implement. Simplicity		E	VG	P	E	G	G	G	S	P	VG	S	S
Cell Balancing Speed		P	VG	E	P	VG	S	VG	V	P	VG	E	E
Cost		E	G	G	G	P	VG	S	G	E	P	S	G
Approx. Efficiency		P	S	G	E	VG	S	G	VG	G	S	E	VG

E: excellent, VG: very good, G: good, S: satisfactory P: poor
Transformer with [#] of windings

M. Kim, J. Kim and G. Moon, "Center-Cell Concentration Structure of a Cell-to-Cell Balancing Circuit With a Reduced Number of Switches," IEEE Transactions on Power Electronics, vol. 29, no. 10, pp. 5285-5297, October 2014.

OPERATION

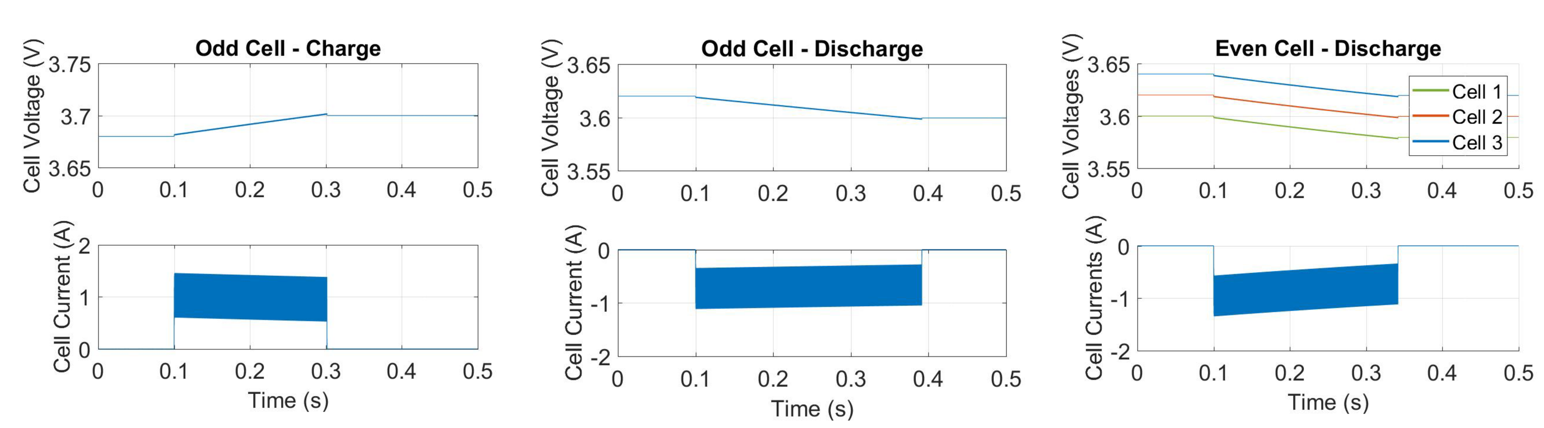


Odd Cells

Odd cells can be selected directly due to their polarity with the DC/DC output.

Even Cells

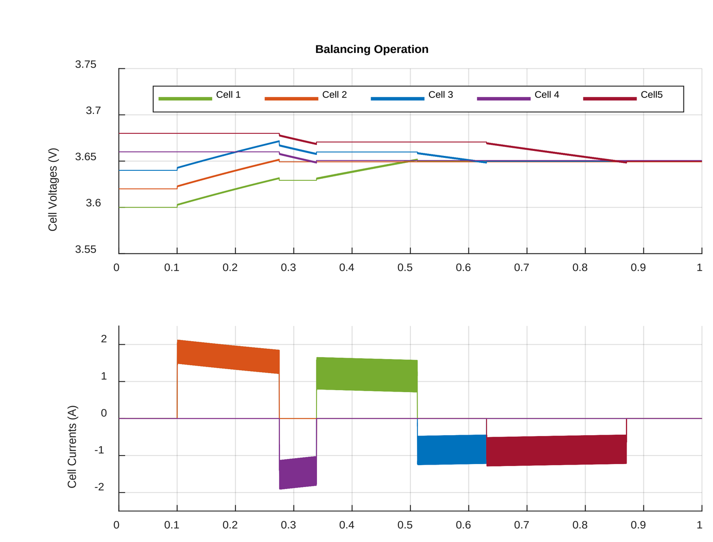
To increase efficiency, bilateral switches were not attached to the DC/DC output, thus making even cells unable to charge directly. They must be changed using a three step process.



PERFORMANCE

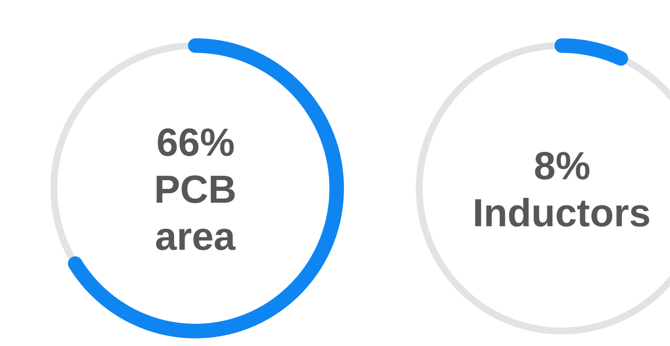
Simulations

Simulations in Matlab/Simulink show that the design is able to move charge to and from the battery string. Optimization of the DC/DC control, including switching frequency, duty cycle, and switch control will be performed to increase the efficiency of the overall circuit.



Experimental

A battery pack with 12 series cells rated at 5.2Ah will be tested with the proposed circuit. An Opal-RT will act as the controller, deciding which cells to charge and discharge. Overall efficiency of each state – odd cell charge/discharge, even cell charge/discharge – will be determined. Preliminary results show that the circuit board area can be reduced by a third when compared to Life Balancing, while using less inductors.



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