

## Cell Balancing in Low Duty Cycle Applications

Voltage distribution in a series stack of ultracapacitors is initially a function of capacitance. After the stack has been held at voltage for a period of time, voltage distribution then becomes a function of internal parallel resistance (leakage current).

For example, consider a stack of 20 capacitors initially charged to 50 volts. If the cells have identical capacitance, the voltage should divide evenly, so that each capacitor charges up to 2.5 volts. If the cells have any variation in capacitance, individual cell voltages will vary based on capacitance. The cells with greater capacitance will be charged to lower voltages, and the cells with smaller capacitance will be charged to higher voltages. This is because each cell conducts the same current, and voltage is a function of current and capacitance. The average voltage will still be 2.5 volts (50 volts / 20 cells).

Any cell at voltage discharges through an internal "parallel resistance". The current through this parallel resistance is referred to as leakage current. The leakage current has the effect of self-discharging the cell.

After some time held at voltage, the voltages on the individual cells will vary based on the differences in leakage current, rather than on the differences in capacitance. The cells with higher leakage should have lower cell voltages, and vice versa. This is because the higher leakage current discharges the cell, lowering its voltage. This voltage must then be redistributed onto other cells in the series (provided the series string is held on a constant voltage source).

One technique to compensate for variations in leakage current is to place a bypass resistor in parallel with each cell, sized to dominate the total cell leakage current. This effectively reduces the variation of equivalent parallel resistance between the cells. For instance, if the cells have an average leakage current of 10uA +/- 3uA, a 1% resistor which will bypass 100uA may be an appropriate choice. The average leakage current will now be 110uA, +/- 4uA. Introduction of this resistor has decreased the variation in leakage current from 30% to 3.6%.

If all the parallel resistances are the same, the cells with higher voltages should discharge through the parallel resistance at a higher rate than the cells with lower voltages. This will help to distribute the total stack voltage evenly across the entire series of capacitors.

The system designer must consider the effect of increased leakage current due to the addition of bypass resistors for balancing. A typical trade is based on time to balance vs. leakage current; the faster the balancing circuit responds, the greater the leakage. A 10:1 ratio of bypass leakage current to cell leakage current may take a few days to balance a severely unbalanced system, where a 100:1 ratio may balance in a few hours. Once the system is balanced, response time is less of an issue unless a system is being severely cycled.

For high duty cycle applications, Maxwell Technologies recommends active balancing. For more information, please contact us at the addresses below.

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