

- **How will Ultracapacitors/Supercapacitors/EDLCs help my product?**

- a. Ultracapacitors have very high specific power which is largely unaffected by temperature through their operational range. When Ultracapacitors are paired with high energy sources, the combined system peak power can increase dramatically.

- **How long will ultracapacitors last?**

- a. Ultracapacitors have a design life of 10 years at rated voltage and 25 °C. Reducing voltage and temperature can increase design life, while increasing temperature and voltage will shorten design life. Most applications will use cells at a lower nominal voltage to get longer design life at higher temperatures.

- **What is the output voltage of an Ultracapacitor?**

- a. An Ultracapacitor only provides energy as its voltage decreases and absorbs energy as its voltage increases. The output voltage is dependent on the state of charge. An upper and lower voltage limit has to be used to determine working voltage range.

- **What voltage can the Ultracapacitors/Hybrid Capacitors be charged to?**

- a. Ioxus Ultracapacitors can be charged from 0.0 VDC up to 2.7 VDC. Ioxus Hybrid Capacitors can be charged from 1.0 VDC up to 2.3 VDC.

- **What is an Ioxus Hybrid Capacitor?**

- a. Ioxus Hybrid Capacitors are similar to lithium ion batteries, except they store charge at the surface of the electrodes instead of within the electrodes. Hybrid Capacitors store more energy than ultracapacitors, but have less power output. Hybrid Capacitors have more power than lithium ion batteries, but less energy storage.

- **How much energy will an Ultracapacitor provide (how long will my application run)?**

- a. Ultracapacitors store much more energy than other types of capacitors, but substantially less than batteries. To determine the energy stored in an ideal capacitor take the upper voltage and square that, then subtract the square of the lower voltage and multiply the result by one half the cell capacitance to get the energy transferred in joules. $E = \frac{1}{2}C \times (V_{upper}^2 - V_{lower}^2)$

- **How much power can Ioxus Ultracapacitors provide?**

- a. Ultracapacitors are power limited only by their ESR or Equivalent Series Resistance. Ioxus Ultracapacitors can be charged or discharged at currents up to 1000C. Ioxus Ultracapacitors can provide peak power densities in excess of 10 kW/kg.

- **How do I charge an Ultracapacitor?**

- a. Ultracapacitors follow strictly current based charging rules. An ultracapacitor cell will absorb as much current as is supplied to it, while its voltage increases based on how much charge it has accumulated. Care must be taken in designs for charging Ultracapacitors at a low state of charge, since they will act like a short circuit when their voltage is near zero.

- **What are the rules for connecting cells in series?**

- a. Most applications require cells to be connected in series to reach higher working voltages. For cells in series, it is best to derate the cells' rated voltages to reduce the impact of unbalanced cell voltages on system life. As identical cells are connected in series, ESR increases as a multiple of the number of cells and capacitance decreases by the quotient number of cells. $ESR_{Total} = ESR_{Cell} \times \# \text{ of cells}$, $C_{Total} = C_{Cell} / \# \text{ of cells}$

- **What are the rules for connecting cells in parallel?**

- a. Cells can be connected in parallel if a capacitance is needed that is larger than an available cell size. Cells of different sizes can be connected in parallel, as long as the same types of cells are used for each series connected unit to match capacitance and ESR. For identical cells connected in parallel, ESR decreases by the quotient number of cells and capacitance increases as a multiple of the number of cells. $ESR_{Total} = ESR_{Cell} / \# \text{ of cells}$, $C_{Total} = C_{Cell} \times \# \text{ of cells}$

- **What is leakage current?**

- a. Ultracapacitors have a small amount of self discharge which is referred to as leakage current. Because of small variations in materials and manufacturing, the leakage current of cells can vary a small amount. Over time as the cells are at a high state of charge, the small variations in leakage currents will cause cell voltages to spread apart. Cells with lower leakage current will increase in voltage as cells with high leakage current will decrease in voltage. Since leakage current increases with voltage, the cell voltages will eventually stop spreading apart when the individual leakage currents become equal, however enough of a spread can exist which can cause the cells at higher voltages to degrade prematurely when the series connected cell bank is at a nominal voltage.

- **What is cell balancing and do I need it?**

- a. Cell balancing is a way to reduce the voltage spread in cell voltages resulting from an imbalance in leakage currents or an imbalance in power losses from ESR. Cell balancing can range from a simple 1% tolerance resistor across the terminals of each cell which is sized to dissipate 10 times the nominal cell leakage current to complex circuits which shuttle charge between cells. In general it is a good idea to have cell balancing for applications requiring long cell life.

- **Can I replace battery XYZ with Ultracapacitors or Hybrid Capacitors?**

- a. Usually no, but there are certain low energy applications such as UPS ride through for generator starting, engine starting, and off-grid LED lighting which can be powered by Ultracapacitors or Hybrid Capacitors without a battery. The use of high efficiency DC-DC converters can greatly extend the working voltage range for increased energy extraction from cells while providing a regulated output.

- **What cell should I use in my application and how many cells do I need?**

Correct sizing of Ultracapacitors for an application takes into account many variables, but there are a few rules of thumb that can be used to estimate requirements. Determine the number of cells required in series by dividing the maximum voltage by the rated cell voltage (or derated voltage) and rounding up. Determine how much energy is required for discharge or how much capacitance base on constant current using the equation for capacitance $C = Q/V$ (Capacitance equals current in amps multiplied by time in seconds divided by voltage change in volts).

Example: 100 VDC to 70 VDC at 145 A, 10 Wh (36000 J) storage.

Capacitance = $2 \times 10 \text{ Wh} \times 3600 \text{ s} / (100^2 - 70^2) = 14.1 \text{ F}$

Capacitance = $130 \text{ A} \times 3 \text{ s} / 30 \text{ V} = 13 \text{ F}$

of Cells = $100 / (2.7 \times 0.95) = 38.9$ cells, round up to 39 cells

Cell size = $39 \times 14.1 \text{ F} = 550\text{F}$ or $39 \times 13 \text{ F} = 507$, round up to closest size: 600 F

- **Does Ioxus have any prepackaged arrays of cells or modules?**

- a. Ioxus is preparing to release several modules. If you have a specific module requirement, our engineers can design one based on your specifications.