Ensure Trouble-Free Supercapacitor Operation with Proper Component Selection Process

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The electronics and electrical power design industry have become hooked-on supercapacitors as long-life, energy storage devices. However, designers who are not familiar with the nuances of supercapacitor operation must carefully evaluate the criteria used in selecting these components if they desire trouble-free energy storage for the lifetime of their particular application.

For this reason, valuable sizing and selection criteria are offered below to provide insight into the first steps in choosing the proper supercapacitors. These are the initial stages used to ensure a lifetime of operation over millions of load cycles.

Designers implementing supercapacitors require basic system requirements to begin sizing. The selection process involves key considerations and calculations that will lead to accelerated circuit design integration. The effects of temperature and equivalent series resistance (ESR) will be introduced and some preliminary equations will provide designers with some insight on how to ensure long life.

To select the right supercapacitor for an application, designers will need to know these four basic requirements:

- Normal operating voltage;
- Minimum operating voltage or cutoff voltage for the device;
- Current or power;
- Duration of pulse or hold-up time.

Ambient temperature profiles will aid in selection. Temperature and voltage are key factors affecting lifetime. Operating temperature range and life will enable a designer to anticipate changes in the capacitor parameters over time and ensure sufficient design margin selection.

Additional evaluation criteria:

- Balancing circuit and cell leakage currents.
- Life/aging due to temperature and time;
- Initial tolerance;
- DC resistance. This is a critical parameter as it affects the effective operating voltage drop and operating temperature rise due to current.

Voltage Drop

During discharge there is initial voltage drop due to the equivalent series resistance (ESR). This is followed by a voltage drop due to the reduction in energy stored. These are known as resistive and capacitive voltage drops and it's important to consider both. The capacitive component represents the voltage change due to the real energy delivered by the supercapacitor. The resistive component represents the voltage change due to the ESR.

Temperature and voltage directly affect the life and aging of supercapacitors. Life extends approximately 2.2 times for every 10 degrees Celsius, 2.2 times for every 0.2-volt (V) reduction, and the Arrhenius plots shown below helps to visualize the temperature and voltage effects. (Note that these values are approximations and vary by manufacturer, design and voltage.)

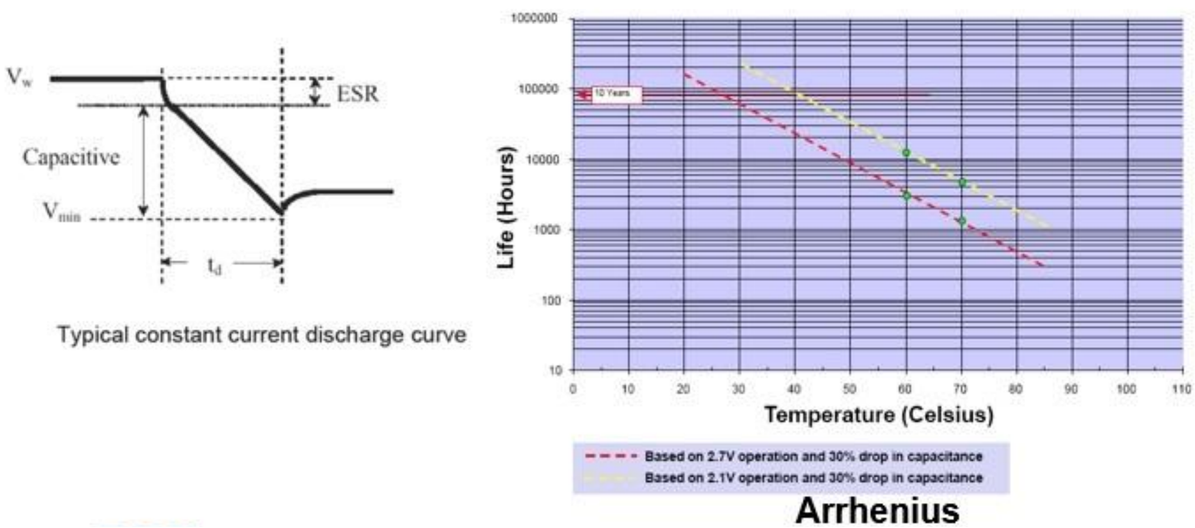

Figure 1 - When sizing supercapacitors, consider voltage drops due to initial current pulse (ESR) and life/aging due to time, voltage, and temperature, as shown in the Arrhenius graph above.

Temperature also has an effect on the operation of supercapacitors. The ESR increases at lower temperatures. Higher ESR will increase the voltage drop and should be accounted for in any design. Capacitance is also affected by temperature, although to a much less extent. Capacitance decreases as temperature decreases and increases as the temperature increases. The initial capacitance tolerance is the possible variation or change of capacitance a capacitor may have from lot to lot and should be considered during the sizing process.

Series or Parallel?

Supercapacitors can be designed in series or in parallel to achieve various voltage and energy levels. Placing capacitors in series will increase the voltage rating by adding the voltage rating of each supercapacitor in series. So, two 2.5 V caps in series will achieve a 5 V rating. However, when placing capacitors in series, the capacitance will decrease and ESR will increase. So, two 5-farad (F) supercapacitors in series will equate to 2.5 F with an ESR that is two times the listed rating.

Energy storage can be increased by placing capacitors in parallel. Capacitance increases by adding the capacitance rating of a cap in parallel. If two 5 F caps in parallel would equal 10 F, the ESR will decrease and the voltage rating will not change.

Useful Equations

There are a few equations used in the initial stages for selecting and sizing. In the examples below, the first solves the initial voltage drop due to ESR, the second solves the initial voltage drop due to capacitance. The third combines equation one and two and will solve for the total voltage drop.

Initial drop in voltage is due to the (ESR):

- The amount of drop is a function of the ESR and discharge current as indicated by the equation below:

  Equation 1: $dV_{ESR} = I_{load} * ESR$

- The capacitor will discharge according to its capacitance:

  Equation 2: $dV_{cap} = I_{load} * t_d/C$

- By placing these two equations together the total voltage drop:

  Equation 3: $dV_{Total} = I_{load} * t_d/C + I_{load} * ESR$

- Equation four solves for the total capacitance value.

  Equation 4:

  $$C_{Total} = \frac{C_{cell} \text{ X \# of Cells in Parallel}}{\text{\# of Cells in Series}}$$

- Equation five $\frac{s}{\text{\# of Cells in Parallel}}$ solves for the total ESR

  Equation 5:

After determining the basic formulas and parameters needed, examples can help a designer work through these calculations. The example below uses a constant current application. To start the designer will initially ignore the ESR effect on the voltage drop to get an estimate on the capacitance and then use Equation 3 to verify if the size picked will work with the ESR effect. Equation 6 is created by removing the ESR portion and rearranging the equation to solve for capacitance.

$$C = I_{load} * t_d/dV_{Total} \qquad \textbf{Equation 6}$$

Using the formula $C = I_{load} * t_d/dV_{Total}$, the result is C= 4*5/(16-9) = 2.86 F. This is the total capacitance at 16 V. Since supercapacitor cells are typically rated at 2.5 V or 2.7 V then, divide the operating voltage

V_{WV} by 2.7 and round up, 16/2.7 = 5.9. This means the designer will need 6 cells in series. Since capacitance divides with cells in series, the designer will need to calculate the capacitance needed per cell.

Designers have several more calculations and considerations to make when selecting the proper supercapacitor for their applications. Supercapacitor calculators available for download make this process easier and the one that Eaton provides is just one example. Visit **www.eaton.com/elx** and click the “Supercapacitor Calculator” link to find out more.